FINAL REPORT

on

GENERAL DYNAMICS/USAF F-16 IMIP MULTI-COMPANY MAGNETICS MANUFACTURING MODERNIZATION FEASIBILITY ASSESSMENT

to

GENERAL DYNAMICS
FORT WORTH DIVISION

May 13, 1988

BATTELLE
COLUMBUS DIVISION
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This report documents the feasibility study performed to identify general cost saving opportunities in magnetics manufacturing and to determine the technical and economic viability of performing "shared" manufacturing technology development that could be used by more than one magnetics manufacturer.

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EXECUTIVE SUMMARY

Wire wound magnetics (inductor) manufacturing is a key cost element and an integral manufacturing activity found within aerospace industries that design, produce, and assemble power related avionics.

The two primary objectives of this feasibility study were to 1) identify general cost saving opportunities in magnetics manufacturing and 2) determine the technical and economic viability of performing "shared" manufacturing technology development that could be used by more than one magnetics manufacturer.

Twelve potential projects have been identified. Not including development, all have less than a 3-year payback. Ten projects return invested capital in less than 1 year. Of the twelve, nine have potential outside the magnetics industry, being applicable to general electronics manufacturing. The remaining three projects are broadly applicable to the magnetics industry.

Potential projects are classified as follows:

Low Capital and Low Development Cost -
($32,500 annual potential savings per company)
- **Wire Stripping Process Definition and Control**
- **Design/Selection of Materials With System View**

Low Capital Implementation Cost With Moderate to High Development Cost -
($537,000 annual potential savings per company)
- **Standardization**
- **Wire Stripper**
- **Wire Marker/Labeler**
- **Wire Tensioner**
- **Insulation Taper Preparer**
- **Product Labeler**
- **Encapsulation Process Definition and Control**

High Development Cost and High Capital Implementation Cost -
($276,900 annual potential savings per company)
- **Automated Full Load Test Facility**
- **Automated Toroid Winder/Manually Assisted Toroid Winder**
- **Automated/Flexible Bobbing Manufacturing Cell**

Other applicable findings:

- Toroid forms dominate the product mix.
- Manufacturing procedures vary widely among those surveyed.
- Major technology development cannot be justified by one company However, the total number of companies required to amortize the development appears to be workable.
- Design and manufacturing of magnetics products is still as much art as science, though the ratio can be improved.
- Most of the vendors surveyed are in the business of magnetics manufacturing primarily to control and achieve delivery requirements.

MATRIX OF OPPORTUNITIES

PROJECT NAME	ESTIMATED DEVELOPMENT COST	CAPITAL COST PER UNIT	NO. UNITS REQ'D	GROSS ANNUAL SAVINGS/ COMPANY	DoD COMPONENT (93.0%)	U.S.A.F. COMPONENT (39.5%)	F-16/SPO COMPONENT (24.4%)
1.0 Standardization	$450,000	$ 0		$295,680	$274,982	$116,794	$ 72,145
2.0 Wire Stripping Process Definition & Control	$ 0	$ 0		$ 20,000	$ 18,600	$ 7,900	$ 4,880
3.0 Encapsulation Process Definition & Control	$250,000	$ Low		$ 59,136	$ 54,996	$ 23,358	$ 14,429
4.0 Design/Selection of Materials	$ 0	$ 0		$ 12,500	$ 11,625	$ 4,937	$ 3,050
5.0 Wire Stripper	$375,000	$ 3,500		$ 64,189	$ 59,696	$ 25,355	$ 15,662
6.0 Wire Marker/Labeler	$225,000	$ 4,500		$ 24,864	$ 23,123	$ 9,821	$ 6,067
7.0 Wire Tensioner	$105,000	$ 3,500		$ 14,955	$ 13,908	$ 5,907	$ 3,649
8.0 Insulation Tape Preparer	$265,000	$ 8,000		$ 10,920	$ 10,155	$ 4,313	$ 2,664
9.0 Product Labeler	$145,000	$ 7,500		$ 13,674	$ 12,717	$ 5,401	$ 3,336
10.0 Automated Full Load Test Facility	$850,000	$165,000		$ 61,152	$ 56,871	$ 24,155	$ 14,921
11.0 Automated and Manually Assisted Toroidal Winder	$800,000	$ 85,000	1	$ 72,200	$ 67,146	$ 28,519	$ 17,616
12.0 Producing Coil Bobbins For Low Quantity Military Applications	$700,000		1	$170,419	$158,490	$ 67,315	$ 41,582

RANK ORDERED RECOMMENDATIONS

Each of the twelve projects is recommended for implementation consideration.

Each of the projects have been individually rank ordered according to the following six categories:

- Development Costs (lowest is 1)
- Development Time (shortest is 1)
- Gross Annual Savings (highest is 1)
- Ratio Savings Dollars to Development Dollars (highest is 1)
- Unit Capital Costs (lowest is 1)
- Ratio of Savings Dollars to Capital Dollars (highest is 1)

Each category has been given equal weight. The table at the end of the "Executive Summary" shows the results. The projects best suited for commercial development are grouped at Level 6. The "Bobbin Coil Fabrication Cell" was assigned a lower rank (Level 7).

1) **Wire Stripping Process Definition and Control**
   Design/Selection of Materials with System View

   With the recognition of potential cost savings, these projects should represent routine configuration control and manufacturing practices within the vendor companies. There should be no development or investment by General Dynamics or the Air Force.

2) **Encapsulation Process Definition and Control**

   Encapsulation practices and associated costs vary dramatically across the electronics industry, as well as among the plants surveyed. The variation suggest that either functional performance (i.e. mission) is impaired, or encapsulation represents a cost saving opportunity for the industry. While this report deals largely with labor savings, this is an area where capital and R & D costs have also been high.

   There are conflicting beliefs about essential manufacturing practices. No one was able to site a definitive document correlating encapsulation procedures with functional performance. For mission and cost reasons, this is a high priority.

3) **Standardization**

Standardization of magnetics offers the mechanism that can enable both vendors of magnetics capital equipment, and the industry's manufacturers to develop their own opportunities. It is the critical catalyst.

Manufacturers are not currently able to classify their product mix, except within broad categories. Justification of equipment and focusing of resources is difficult to rationalize. Standardization can facilitate automated design, automated process planning, automated manufacturing, reduced lead times, minimized inventory and faster deliveries.

4) **Full Load Automated Testing**

This is a low technical risk opportunity with applicability within and outside the magnetic industry. Savings were identified based on direct labor only, though this equipment would obviate other test equipment.

Full load testing would limit the current practices of adding value to defective parts, both within magnetics manufacturing departments and prior to assembly. This is envisioned as a flexible, high speed programmable piece of equipment.

5) **Automated and Manually Assisted Toroid Winder**

There have been no fundamental changes to commercial toroid winding technology in the last 50 years. Current processes have a large labor component with associated problems achieving uniform production.

There is a shift to increased toroid production due to the increased product performance requirements characteristic of DoD aerospace electronics. A manufacturing breakthrough is essential.

6) **Wire Tensioner**
Wire Stripper
Wire Marker/Labeler
Product Labeler
Insulation Tape Preparer

All five of these projects represent low technical risk and are broadly applicable to the electronics industry. With encouragement, it may be possible to entirely fund these among equipment suppliers and users.

A tensioner is an important part of both semi-automatic and automatic winding processes. Current tensioners are not used either because they are perceived to not be effective, or because they are time consuming to set up.

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PER: MR. DONALD BRUHN

Commercial vendors cffer working tensioners in the $1000 range. The primary issue here is being sure that users recognize the costs associated with not using tensioning devices. Development costs in this proposed project represent a more "user friendly" tensioner.

7) **Producing Coil Bobbins for Low Quantity Military Applications**

While this is clearly an attractive project from a financial perspective, it has been assigned a low priority due to the unmanageable product variety in the industry. Completion of project with maximum utility is predicated on successful implementation of the "Standardization" project.

While Battelle has not revealed the contents of this report to any vendors, we have approached several vendors about the possibility of participating in a joint development program. All responses were enthusiastically positive.

One caveat is that most of the major manufacturers of winding equipment are foreign based, with U.S. sales representation only.

RANKING PARAMETERS USED IN DEVELOPMENT OF RECOMMENDATIONS

Abbreviated Project Name	Development Costs	(1) Development Costs Rank	Development Time (Months)	(2) Development Time (Months) Rank	Gross Annual Savings Per Company	(3) Gross Annual Savings Rank	Savings Dollar per Develop. Dollar	(4) Savings Dollar per Develop. Dollar Rank	Capital Costs Per Unit	(5) Capital Costs Per Unit Rank	Simple Payback (Years)	Savings Dollar Per Capital Dollar	(6) Savings Dollar Per Capital Dollar Rank	Composite Rank	Unique To DoD Magnetics Industry	Common DoD Need	Rank Ordered Recommendations
Wire Stripping	$0	1	3	1	$20,000	8	2.00E+13	1	$0	2	0.00	2.00E+13	1	14	Yes	Yes	1
Materials Selection	$0	2	6	2	$12,500	11	1.25E+13	2	$0	3	0.00	1.25E+13	2	22	Yes	Yes	1
Standardization	$450,000	9	30	11	$295,680	1	6.57E-01	3	$0	1	0.00	6.57E-01	3	28	Yes	Yes	3
Wire Tensioner	$105,000	3	12	3	$14,955	9	1.42E-01	7	$3,500	5	0.23	1.42E-01	7	34	No	Yes	6
Encapsulation	$250,000	6	12	4	$59,136	6	2.37E-01	5	$25,000	9	0.42	2.37E-01	5	35	Yes	No	2
Wire Stripper	$375,000	8	24	9	$64,189	4	1.71E-01	6	$3,500	4	0.05	1.71E-01	6	37	No	Yes	6
Wire Marker	$225,000	5	16	6	$24,864	7	1.11E-01	8	$4,500	6	0.18	1.11E-01	8	40	No	Yes	6
Bobbin Coil Fab Cell	$700,000	10	30	12	$170,419	2	2.43E-01	4	$150,000	11	0.88	2.43E-01	4	43	Yes	No	7
Product Labeler	$145,000	4	14	5	$13,674	10	9.43E-02	9	$7,500	7	0.55	9.43E-02	9	44	No	Yes	6
Toroid Winder	$800,000	11	24	10	$72,200	3	9.02E-02	11	$85,000	10	1.18	9.02E-02	10	55	No	Yes	5
Tape Prep Cell	$265,000	7	18	7	$10,920	12	4.12E-02	12	$8,000	8	0.73	4.12E-02	12	58	No	Yes	6
Automated Tester	$850,000	12	20	8	$61,152	5	7.19E-02	10	$165,000	12	2.70	7.19E-02	11	58	No	Yes	4

Notes:

1. Composite Rank is the sum of 1) Development Costs Rank, 2) Development Time Rank, 3) Annual Savings Rank, 4) Savings/Development $ Rank, 5) Capital Costs Rank and 6) Savings/Development $.
2. Wire Stripping and Materials Selection are viewed as approximately equal minimal development/minimal capital project opportunities.
3. Encapsulation is a low risk, modest capital cost project that can return substantial returns.
4. The Wire Stripper, Wire Tensioner, Wire Marker, Product Labeler, and Tape Preparation Cell are recomended for commercial development. Hence are "down graded" in the ranking for AF sponsorship.
5. The Coil Bobbin Fabrication Cell is rated last due to lack of common DoD need, highest development and implementation risk, and "linkage" to successful completion of Standardization program.

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INTRODUCTION

A key cost element in producing power electronics for aerospace is the cost of manufacturing the wire wound magnetic devices. The objective of the feasibility study was to determine the technical and economical viability for performing "shared" manufacturing technology development that could be utilized by more than one magnetics manufacturer.

For the past seven years, the General Dynamics/Fort Worth Division Industrial Technology Modernization (ITM) Program Offices, in conjunction with the U.S. Air Force F-16 System Program Offices (SPO), has been assisting in modernization of F-16 subcontractor's facilities. In a cooperative effort, General Dynamics and the U. S. Air Force have sponsored an IMIP "Multi-Company" Phase 1. This program was designed to maximize the discovery of opportunities in an entire industry segment, at minimum cost.

Battelle served as an independent third party with responsibility to protect the proprietary information of individual magnetics manufacturers, while developing a composite industry profile. Battelle is neither a manufacturer nor a marketer of magnetics related products--yet is experienced in the application of emerging, as well as mature, technologies to manufacturing.

Four power related avionics subcontractors (Aerospace Avionics, Bohemia, NY; Eldec, Lynnwood, WA; Pacific Electro Dynamics, Redmond, WA; and SCI Technology, Huntsville, AL) participated with Battelle to jointly scope generic project(s) to advance the state-of-the-art (SOA) in the manufacturing of F-16 magnetics. Special thanks to the Robert M. Hadley Company, Inc. located in Los Angeles and AT&T New River Division for allowing the project team to review their magnetics operations. The factory tours and subsequent discussions were of great assistance in developing the "Generic Company" profile.

The development projects identified by this program are generic in nature so that, with modifications/ and integration, the technology may be used by the participating subcontractors and is transferrable to other companies, both DoD and commercial, that manufacture magnetics.

The simplified tasks of this preliminary feasibility assessment are to:

- Profile current magnetics operations including cost data,
- Determine commonality of processes and product fabrication criteria for magnetics, and
- Identify potential manufacturing enhancements (with associated development costs)

The scope of this assessment included all manufacturing, parts fixturing, materials handling, tooling, testing and inspection for the manufacturing processes used in production of magnetics. The depth of analysis includes estimates by Battelle specialists in manufacturing modernization and equipment design. Overview information, functional cost analysis and considered expert opinion was used to identify potential improvements in manufacturing methods and processes and their estimated costs.

Throughout this feasibility study, Battelle worked closely with General Dynamics' ITM Program Office staff. In addition to periodic reviews, deliverables from this contract may be summarized as follows:

- Description of the developed magnetics industry data
- Listing of all improvement concepts with descriptive narrative
- Concept impact assessments
- Preliminary concept cost/benefit analyses
- Prioritized listing of recommended ITM Phase II projects with development and cost/benefit information required to prepare appropriate Phase II proposals

As appropriate, Battelle has provided comments on the State-of-the-Art technology and recommendations regarding alternative processes for possible implementation into the magnetics industry.

In preparing this report, it was assumed that users would have a basic familiarity with magnetics products used in avionics.

GENERAL OBSERVATIONS/CONCLUSIONS

A substantial finding of this project is verification that there are common requirements among the "low volume" magnetics manufacturers. The areas for opportunity cover the entire magnetics manufacturing process. With few exceptions, capital equipment being marketed to the magnetics subcontractors is not substantially different than that available 25 or more years ago.

An important additional finding of this project is that there is not consistent application of the existing vendor equipment and "process technology". There are no "industry-wide guidelines" or "best practices" available to assist these companies to optimize product design for manufacturability.

Magnetics manufacturing cost reduction can be achieved through:

- Application of current state-of-the-art manufacturing technology, and
- Adherence to design/manufacturing standards developed to meet both design and cost requirements.

Part of the scope of this report is an assessment of proposed technical opportunity and economic feasibility. Detail (and proprietary) data was obtained from the four participating DoD magnetics subcontractors. Visits to an additional DoD/military and commercial magnetics manufacturer as well as discussions with numerous equipment suppliers were completed. Because this information cannot be shared, a "Generic" or "Model" magnetics manufacturing organization has been developed. The data from this "company" is used to evaluate opportunities developed by Battelle. This report does not attempt to estimate the size of the market beyond the four participating companies. However, based on discussions with vendors, it is believed that the "Generic" organization presented in this report is typical of substantially more than four companies. The description of the "Generic" magnetics organization and other information contained in this report can be used to further develop the corroborating data needed to proceed with work aimed at assisting this industry segment.

GENERIC COMPANY SUMMARY

The Generic company is a "rounded" average based on the four participating companies. Appendix 2A provides more detail.

The typical Magnetics Department has 55 direct labor personnel. Annually they produce 86,000 transformer/inductor coils. These coils are the principal component needed to build the transformer sub-assembly. These coils are of two basic configurations; toroids and cylinders. The cylindrical coils have two major types; bobbins and core tubes. An illustration is shown in the following figure. The typical annual product mix is as follows:

- Toroids - 57,000 (66.28% of mix)
- Bobbins - 10,000 (11.63%)
- Core Tubes - 19,000 (22.09%)

The direct labor to produce the completed transformer sub-assemblies is apportioned into the following functions. A flow chart illustrating the interrelationships of the functions is at the back of this report.

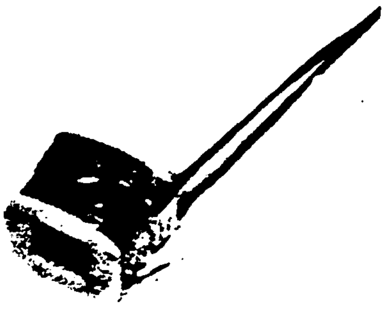
- Kitting - 1 Person
- Winding - 13 Persons
- Post Winding Assembly - 21 Persons
- Encapsulation - 11
- Testing - 7 Persons
- Material Handling - 2 Persons

The next table shows an apportionment of the direct labor costs by function and commodity. Note that labor-hours have been priced at $8.00. For the typical IMIP Cost-Benefit-Analysis (CBA), the rate would include the variable manufacturing overhead. For the generic company the "loaded" rate is $14.00 per hour.

COIL CONFIGURATIONS

TOROID

BOBBIN



CORE TUBE

SUMMARY OF DIRECT LABOR COSTS/UNIT
BY COMMODITY BY PROCESS FOR GENERIC ORGANIZATION

(Based on Annual Production of 86,000 Coils and Direct Labor of $8.00/Hour)

Process	Toroids		Bobbins		Core Tubes	
KITTING	$0.19		$0.19		$0.19	
WINDING	$1.62		$4.05		$4.05	
Machine		$0.18				
Manual		$0.37				
Wire Stripping		$0.14		$0.34		$0.34
POST WINDING ASSEMBLY	$4.27		$1.42		$4.27	
Wire Tinning		$0.19		$0.06		$0.19
Wire Stripping		$0.58		$0.19		$0.58
ENCAPSULATION	$2.06		$2.06		$2.06	
TESTING	$1.25		$0.62		$1.87	
TOTALS	$9.39		$8.34		$12.44	

A concluding description of the "Generic" company concerns its customer base. The data presented in this report can additionally be interpreted as the "Generic F-16 Avionics Subcontractor Who Manufacturers Their Own Magnetics". Sales statistics for the generic company are as follows:

- 93.0% of Sales are DoD
- 39.5% of Sales are Air Force
- 24.4% of Sales are AF/F-16

The Cost Benefits Analysis (CBA) performed during this feasibility assessment assumes that the percent market share applies to all part designs equally. Hence when evaluating a given improvement to determine impact to DoD (93.0%), Air Force (39.5%), and AF/F-16 (24.4%) the market share is applied to the annualized savings per company.

A complete profile of the generic company is contained in Appendix 2. There are overlaps between some process "functions". For example, some companies perform encapsulation preparation as a post winding assembly

activity. Other companies incorporate encapsulation preparation into the encapsulation function. The next section summarizes the opportunities shared by the four participating subcontractors and other magnetics manufacturing operations visited.

SUMMARY OF MAGNETICS OPPORTUNITIES

This investigation was limited to the magnetics manufacturing shop floor. Hence improvement opportunities that may exist in "transition" activities such as process planning or procurement ("make" vs "buy") are not included.

The generic functional activities that describe the complete magnetics manufacturing process are:

- Kitting
- Winding
- Post Winding Assembly
- Encapsulation
- Testing

Additional subjects are addressed under a "General" category (and presented first). A summary discussion on each function is presented followed by a table of the identified magnetics manufacturing cost reduction opportunities.

GENERAL

The DoD/Military magnetics manufacturer is a low volume supplier. Lot sizes can be as low as 1, as large as 100, and typically are 20-30. Very limited standardization exists between designs. The inability to develop standardized designs is attributed to the technical performance, including physical size required of the magnetics transformer component of the avionics system. It is believed that standardized "design families" could be developed that could satisfy the design requirements in the majority of instances. Manufacturing technology could then be focused to economically produce these design families.

KITTING

Kitting was a low cost effort for each contractor.

WINDING

Winding represents one of the primary opportunities for development which would be attractive to all the subcontractors. Two-thirds of the coils produced are toroids. This varies from a low of 58% to a high of 90% among the four subs. The manufacturing technology for toroidal winding has not significantly changed in 40 years. Yet, toroids are the principal component of the present workmix and due to increasing performance requirements are forecast to become an even greater share of the future product mix.

In this report the winding function is limited to activities needed to support completion of winding the coil. Analysis of the three basic coil configurations reveals that there are significant differences in the activities required to support winding.

Toroidal winding is substantially a wire winding process. The generic company "hand winds" over 15,000 coils each year.

Bobbin winding is a predominantly wire winding plus insulation taping activity. Precise automatic bobbin winders are available to locate the wire during winding with consistent tensioning. However, these machines do not incorporate the ability to apply the various insulation tapes. In most cases, the bobbin (as ordered from the catalogue) must be modified (flanges trimmed, slots for wire leads added, etc.). There were no examples of the low volume supplier using automated wire winding equipment to terminate wire leads onto terminal pins integral to the bobbin.

Core tubes require bobbin fabrication, as well as winding and insulation common to bobbin winding. Core tubes tend to be physically larger than bobbins. The "core tube" provides the maximum flexibility to the magnetics designer. However, having greatest flexibility, also implies greatest expense.

The cost data associated with the existing "bobbin" and "core tube" fabrication are similar for different reasons. In bobbin winding, the catalogue bobbin is modified to conform to the designers requirements. In core tube winding, the "equivalent bobbin" is fabricated (as an intra-winding activity) along with the actual wire winding. Insulation is applied at various points during the winding operations. These tapes are manually prepared by marking and cutting from a larger tape or sheet of insulating

material. With some styles of product as much as 15% of the winding labor can be in insulation tape preparation.

POST WINDING ASSEMBLY

There is a large dissimilarity within this function among the four participating subcontractors. This is mainly due to the wide diversification of the transformer sub-assemblies. Design variables include the method chosen to mount the transformer in the avionics system and method for heat transfer from the coils. The variation between companies is sufficient to preclude any group technology for "automated assembly". However within the Post Winding Assembly function there are processing sequences that are independent of configuration and hence are common requirements. These include wire stripping, tinning, terminating, and marking.

Wire stripping is a significant cost within the generic magnetics manufacturing organization (7.68% of total direct labor budget, approximately 4.225 equivalent persons at any one moment). A comprehensive program to reduce stripping practice is needed.

Most of the wire stripping is accomplished by mechanically removing the insulating coating. The wire insulation can also be removed thermally. The temperature of the heated solder in the solder pot/bath is sufficient to melt the coating from the wire during the tinning sequence. Wire is rated according to the maximum operating temperature conditions. Different temperature classes of wire have different insulation coatings. Low temperature wire (rated 180 C and below) can conveniently be stripped and tinned simultaneously in a solder pot. The 220 C (and some types of 180 C) wire must be mechanically stripped.

Attention should given to minimize the extent of the remaining mechanical stripping. Workers were observed stripping two to five inches of insulation from leads when one-half inch or less would be sufficient.

> **IMPORTANT: Significant cost savings, possibly exceeding $80,000 annually, can result from better control of wire stripping. In all observed cases, wire was stripped by individual wire, even when combined with a tinning operation. Where solder stripping is used, multiple wire can be simultaneously stripped.**

Additionally, excessive lengths of wire were routinely stripped. The primary reason given was to ensure that stripped ends were available after the wire was cut to length in assembly. Given the stripping costs, wire lengths should be established and maintained during initial fabrication.

Termination leads are currently hand marked. Sometimes preprinted tapes are wrapped around the wires.

An additional common need was for more consistent and controllable core binding equipment. Cores are sometimes banded with a metallic, usually stainless steel band. The current operation is very labor intensive and a source of rework due to the uncontrollability of the present process.

ENCAPSULATION

Encapsulation is a processing sequence that is not consistently or commonly applied by the four subs. There were differences; both when comparing company to company and when comparing encapsulation practices within a given company. The lack of established consensus represents an opportunity for "industry wide" cost reduction.

TESTING

There is not an identifiable end use quality problem present. In part this is due to the 100% testing that exists at several points along the magnetics fabrication process. The electrical testing typically is performed using basic instruments such as a calibrated power supply, volt meters, ammeters, insulation testers, and CRTs. It is common to see utilization of a part/component specific test fixture to facilitate wiring the coil prior to test. In many instances, the test fixture has been designed to accommodate a "family" of similar designs. The industry practice generally is to not simulate the electrical "load" onto the assembled transformer component. This test is performed integral to the "avionics" system testing. The disadvantage to performing the "full load" test at the later date is late identification of fabrication problems.

Commercial manufacturers, including high and low volume, are making more use of full load test equipment.

The following table summarizes the Magnetics Manufacturing Opportunities identified during this program.

SUMMARY OF MAGNETICS MANUFACTURING OPPORTUNITIES

Opportunities Requiring No Capital for Vendor Implementation -

- Standardization
- Wire Stripping Process Definition and Control
- Encapsulation Process Definition and Control
- Design/Selection of Materials

Opportunities Requiring Significant Development and Modest (<$10,000) Unit Implementation Cost.

- Wire Stripper
- Wire Marker/Labeler
- Wire Tensioner
- Insulation Tape Preparer
- Product Labeler

Opportunities Requiring Significant Development and Significant Vendor Capital Investment.

- Automated Full Load Test Facility
- Automated Toroid Winder
- Automated Bobbin Winder

DESCRIPTION OF CANDIDATE PROJECTS

This section presents detail description of projects considered for development. The information presented for each project is as follows:

- Project Description/Objective
- Background
- Benefits
- Estimated Development Cost
- Implementation

1.0 STANDARDIZATION

1.1 Project Description/Objective:

Both functional and notational standards need to be developed for all three major types of magnetics products including toroids, bobbins, and core tubes. These standards would be extended in the future to surface mount devices (SMD). This is an all industry need, not simply an aerospace need.

Functional standards include configuration and performance parameters. Notational standards are needed to create the kind of engineering and manufacturing database that will expedite the use of the standards and automated design.

1.2 Background:

Since there are currently no magnetics design standards, product mixes are not accurately known. It is expensive to determine whether a previous design, or slight modification may suffice in a new product. In this industry design is as much art as science. Manufacturing methods are manually based and the benefits of automation are difficult to economically justify due to the varying product mix.

Magnetics production for internal use is driven largely by product and prototype (test sample) availability requirements. Interviews suggest that power supply vendors would prefer to outsource their magnetics, but are unable to live with routine delivery schedules.

1.3 Benefits:

Standards would accelerate parts acquisition and reduce the cost of both design and manufacturing. This contributes in both initial product manufacture and ongoing maintenance. A 20% reduction in

total direct labor costs for the generic company represents annual savings of $168,960 (unburdened), $295,680 (burdened).

1.4 Estimated Development Cost: $450,000

Development and coordination of a consensus standard, with a focus on function and notation for aerospace applications is estimated to cost $450,000. This cost assumes that interested parties, such as manufacturers, would contribute and participate at their own expense.

Calendar time is estimated at 30 months to completion.

1.5 Implementation:

The standard would form the foundation for design and manufacturing activities on both an industry and company by company basis. It would expedite and facilitate automated design, the use of expert systems in design, automated process planning, automated manufacturing, and automated testing.

2.0 WIRE STRIPPING PROCESS DEFINITION AND CONTROL

2.1 Project Description/Objective:

The objective of the project is simply to rationally set and enforce wire stripping standards and equipment usage.

2.2 Background:

Wire stripping as a manufacturing process tends to be performed at the judgement of the operator. Lengths stripped, whether mechanically or thermally, tended to vary, and in some cases were clearly excessive. In observed operations, lengths to five inches were laboriously stripped, then clipped and discarded in the subsequent operation. No use for the excessive stripping was identifiable. These are simply expensive oversights.

Solder pot stripping usually involved static liquid solder which is subject to gradual contamination. Commercial equipment such as flow solder pots and pots with skimmers are available.

2.3 Benefits:

For the generic company, wire stripping represents 7.68% of their total direct labor costs. On an annual basis this becomes $64,896 (unburdened, $113,568 (burdened). This project would provide lower reduced direct labor costs and improved quality. Direct labor savings for the four subcontractors should exceed $80,000 annually, based on project surveys, with over $40,000 from one vendor alone.

2.4 Estimated Development Cost:

No extraordinary costs to either General Dynamics or the Air Force are anticipated. On awareness, vendors should be able to perceive cost reduction benefits to their operations and proceed on their own.

Calendar time is estimated at 3 months to completion.

2.5 Implementation:

Each vendor should review process sheets for rational stripping standards and audit operational conformance to those standards.

Where solder stripping/tinning is utilized, new equipment or skimming and filtering techniques should be examined.

3.0 ENCAPSULATION PROCESS DEFINITION AND CONTROL

3.1 Project Description:

Rationalize, define and control encapsulation (potting) practices.

3.2 Background:

Encapsulation practices among manufacturers vary dramatically in labor and equipment requirements for similar performance (end use) requirements. All practices may be adequate, but some are far more expensive than others.

3.3 Benefits:

Encapsulation is important to the mission performance of the magnetics components. Cost is important to mission achievement as well.

Rationalizing this manufacturing practice will contribute to the assurance of mission performance at minimum cost. The generic company has 11 persons supporting encapsulation. A 20% reduction represents an annual savings per company of $33,792 (unburdened), $59,136 (burdened).

3.4 Estimated Development Cost:

The project has two components: adequacy of practice and then cost effectiveness.

Adequacy of practice determination would cost an estimated $250,000. This would be expected to form the foundation of a military standard.

Calendar time is estimated at 12 months to completion.

Cost effectiveness implementation should be by vendors in their own self interest.

3.5 Implementation:

Adequacy of practice would involve a series of tests comparing full load performance of the component with at least three identified major variances in manufacturing practice.

Results of the test would allow the individual vendors to select optimum manufacturing practices to meet end use performance requirements. Alternatively, designers could specify the applicable standard.

4.0 DESIGN/MATERIALS SELECTION

4.1 Project Description/Objective:

Rationalize specification and materials selection, including alternate materials, for the manufacturing of magnetics.

4.2 Background:

Approved materials and alternates were observed to sometimes exceed performance requirements. Alternates, such as high temperature wire (220 C), created additional manufacturing problems and costs as well as the higher cost of the raw material.

While we were able to identify clear cases of over-selection of materials, manufacturing typically does not have access to design specifications, so overspecification was not as easy to verify.

4.3 Benefits:

Since both over specified and over-selected materials increase material and manufacturing costs, cost reductions can be expected. Evidence from the plant surveys suggest that these are good faith decisions made without a full understanding of their cost impact.

Hard data was simply not available to accurately estimate direct cost savings. Close attention to materials specification and selection could save an estimated 15% annually among the surveyed vendors through material and processing cost reductions. This benefit is estimated to be a total of $49,500 annually for the four subs.

4.4 Estimated Development Cost:

There is no identifiable cost to General Dynamics or the Air Force associated with this project. It should be vendor driven, and a

natural, deliberate, part of the disciplined process of releasing a design to manufacturing.

Calendar time is estimated at 6 months to completion.

4.5 Implementation:

Costs associated with material design, selection and substitution decisions should be fully recognized as part of the release decision as well as engineering changes. This includes such variables as material costs, inventory turnover and processing costs.

Recognizing those costs will result in different, less costly selection decisions.

5.0 WIRE STRIPPER

5.1 Project Description/Objective:

A universal wire stripper, capable of rapidly stripping magnetics wire, regardless of its insulation type, is needed. It must leave the bare wire clean, or tinned, and free of both scratches or reduced area.

The ideal universal stripper would be able to handle wire sections that are other than round, and could handle multifilar wires as well.

5.2 Background:

Stripping wire in a solder pot, providing simultaneous tinning, is currently the most rapid method. It does not work for higher temperature insulators.

While there are higher temperature, electrically effective solders which could be substituted, they tend to be gold based, and expensive. There is also the risk at higher temperatures of base metal damage.

5.3 Benefits:

The primary benefit would be the elimination of labor intensive mechanical stripping and its associated cost and quality impact.

The estimated cost reduction compared to current mechanical stripping is 85%. Mechanical stripping is an estimated 66.6% of all stripping practice. The balance being solder pot stripping. For the generic company, wire stripping is estimated at 7.68% of the direct labor budget. Of the 55 direct labor persons in the generic organization, 4.225 equivalent persons are stripping wires at any given time. Hence 2.81 equivalent persons are currently mechanically stripping

wire at the generic company. This project would reduce this figure to .422 equivalent persons stripping wire. This represents a savings per company, of 2.39 persons. Annualized, this is a savings of $36,680 (unburdened), $64,189 (burdened) per company.

5.4 Estimated Development Cost:

$375,000

Development costs for a piece of desk top equipment, through three beta site, working pilot models is $375,000.

Calendar time is estimated at 24 months to completion.

Unit selling price is estimated at $3,500.

5.5 Implementation:

A desk top unit with small opening for wire insertion is ideal. A 2 second max cycle per lead is probably achievable. More than one lead may be accommodated per cycle, depending on the technology employed.

6.0 WIRE MARKER/LABELER

6.1 Project Description/Objective:

A desktop machine capable of creating a wire marker label and, in some cases, installing it on the wire is needed.

Although it stands alone as a project, this is a potential enhancement to the fully automated production cell for any of the three types of magnetics products.

6.2 Background:

Magnetics components have multiple leads that require labeling in order to complete the manufacturing, testing and assembly process accurately.

Current practice is to create either hand written labels, or to use pre-printed labels, and wrap them around the wires. The majority of label preparation is done by hand due to the variety of labels required for the many components. This is both time consuming, and a source of error.

6.3 Benefits:

Cost reductions due to both reduced labor and fewer errors can be achieved. Additionally, more flexibility in labeling may facilitate testing and assembly through the use of more descriptive labels.

Labeling costs are an integral part of the winding cost accounting and were not separately accessible. Our estimate is that 3.36% of the direct labor in the generic company is involved in label preparation and installation, and that this could be reduced by 50%. This benefit represents an annualized savings of $14,208 (unburdened), $24,864 (burdened).

6.4 Estimated Development Cost:

$225,000

We believe that most, if not all, of the technology required exists, off the shelf, but has never been integrated for this purpose.

Estimated costs include 3 beta site pilot products and additional marketing work to determine assure that functional requirements have been identified.

Calendar time is estimated at 16 months to completion.

Unit costs are estimated to be $4,500.

6.5 Implementation:

A microprocessor driven programmable desk top unit would be capable of preparing either individual tape markers, or a series of markers. A marker could then be either removed and installed manually, or the wire to be marked could be inserted in the machine for automatic installation.

If used at the kitting point, one unit may be sufficient for the average company.

7.0 WIRE TENSIONER

7.1 Project Description/Objective:

This is a device designed to be applied in series with exiting and future automated winding machines to provide reliable, precise wire tension and positioning as wire feeds from supply spools.

7.2 Background:

Most current successful semiautomatic winding practices use hand tensioned and positioned wire. While this is functional, it leads to wire breakage and inconsistent product. Such breakage can occur after most manufacturing is already complete.

In the surveyed plants, most tensioners were disabled, or bypassed.

7.3 Benefits:

The primary benefits are improved product consistency and reduced breakage with its associated loss.

This is an essential component for fully automated magnetics production.

None of the vendors surveyed accounted for in process breakage or rework as a separate item, though all complained about tensioners and wire breakage. If comprehensive use of wire tensioners reduced scrap by a net 1%, the annualized benefit would be $8,546 (unburdened), $14,955 (burdened).

7.4 Estimated Development Cost:

$105,000

Included are two beta site operating pilots of the design.

Calendar time is estimated at 12 months to completion.

Unit costs are expected to be $1,500 - 3,500 with higher cost units offering positioning.

7.5 Implementation:

These devices are expected to have primary application in series with existing semiautomatic winders and the future generation of fully automated winding systems.

8.0 INSULATION TAPE PREPARER

8.1 Project Description/Objective:

Automatic preparation of interwinding insulation tapes is needed.

8.2 Background:

Current practice is to manually prepare insulation tapes by preparing a layout on a sheet of insulation material and cutting it with an a razor knife.

This is time consuming, and leads to inconsistent dimensions.

8.3 Benefits:

The primary benefit is reduced direct labor for tape preparation. This is also an essential technology input to a fully automated winding cell.

Insulation taping is estimated at 12.5% of winding total labor (1.625 equivalent persons) for the generic company. Tape preparation is assumed to be half of the total time or .8125 equivalent persons. This project is asssumed to reduce tape preparation time by 50%. This results in a net savings of .41 persons which, when annualized, is $6,240 (unburdened), $10,920 (burdened).

8.4 Estimated Costs:

$265,000

Development costs include 3 production pilots for beta site testing.

Calendar time is estimated at 18 months to completion.

Estimated unit cost is $8,000.

8.5 Implementation:

A programmable desk top unit is envisioned, which could be shared by more than one operator. It would produce a sheet, or strip, of pre-marked, pre-scored insulation tapes.

In optimum usage, the insulation tapes would become a part number, kitted with the basic parts.

9.0 PRODUCT LABELER

9.1 Project Description/Objective:

A machine would provide an automated labeling of the finished sub-assemblies and magnetics assemblies. This equipment could form a component of a fully automated winding cell.

9.2 Background:

At the completion of a component, a hand stamp is made up to mark the individual assembly with a part number. Stamp assembly is time consuming.

9.3 Benefits:

Benefits include reduced labor, accurate and clearer marking. Assembly identification is 5% of Post Winding Assembly for the generic company (or 1.05 equivalent persons). A 50% productivity improvement would result in annual savings of $7,757 (unburdened), $13,674 (burdened).

9.4 Estimated Development Cost:

$145,000

Cost includes two beta site prototypes. Unit cost of the production labeler is estimated at $7,500.

Calendar time is estimated at 14 months to completion.

9.5 Implementation:

A desk top unit with two color (light and dark) dot matrix marking device is envisioned. Typing the part number on a keyboard and positioning the part is required. Initiating the sequence would automatically label the part.

10.0 AUTOMATED, FULL LOAD TEST STAND

10.1 Project Description/Objective:

A convenient method of rapidly testing finished components is required. Current technology exists, but is not convenient and rapid for the wide variety of configurations supported by the surveyed vendors.

A key part of the development is a convenient method of attaching the lead wires of the component to the test equipment. A second issue is the ability to generate an automatic test sequence.

10.1 Background:

The difficult and time consuming nature of individual component testing using current equipment results in no complete functional test until the component is installed at a higher level.

Current practice is to verify turns ratio, and usually an insulation test.

10.2 Benefits:

A convenient test stand would permit testing at the component level, including before and after encapsulation. This would minimize value added to defective products and limit losses to magnetics due to test failure of the completed product.

Estimated magnetics failures in the fully assembled product were 2%. "In-Process" and "Final Inspection" represent 65% of the total Testing requirements. This is equivalent to 4.55 equivalent persons. The labor savings of this project is 50% of this for an annual labor benefit of $34,944 (unburdened), $61,152 (burdened).

10.3 Estimated Development Cost:

$850,000

One beta site pilot is included in the development cost.

Calendar time is estimated at 20 months to completion.

Unit selling price is estimated at $165,000.

10.4 Implementation:

A desk sized unit is envisioned which would be manually loaded with the test component, including manual placing of component leads. The unit would be preprogrammed to conduct a series of load, insulation and turns ratio tests. Results would be automatically compared to expected standards and available on CRT, printout, uploadable or storable. Techniques such as statistical quality control could be applied.

11.0 AUTOMATED AND MANUALLY ASSISTED TOROIDAL WINDER

11.1 Project Description/Objective:

Develop an improved toroidal winding machine which can handle toroids with I.D.s too small to accommodate a shuttle. The machine development program would concurrently develop an automatic and manual assisted model. This machine concept would also be used for heavier gage wires currently not practical for the small shuttle machines. Two basic models based on wire sizes handled may be required for the overall ranges expected.

11.2 Background:

Currently, there are three basic methods for winding toroids. These are 1) Hand Winding, 2) Shuttle Winding, and 3) Hook Winding. Present toroid winders have several limitations regarding their use in the observed low quantity production of high quality coils: 1) Heavy gage wire (relative to core size) cannot be wound by shuttle type machines for two reasons; a) The wire required will not fit on a shuttle that is small enough to pass through the small center clearance usually encountered, b) The shuttle unit often cannot provide sufficient tension to closely wind the heavier wire coil. 2) Standard "shuttle type" toroidal winders cannot handle multifilar coils of more than about 3 wires. The standard toroid winders work effectively for producing fairly high quantities of toroids for the typical wire and core sizes for which they were developed. However, even with these "typical" toroid coils there is often a significant set-up procedure which must be performed by a skilled operator. Wire breakage and tensioning problems are common.

Shuttle type toroidal winders are offered by several companies in the United States including: Gorman, Universal, Tanac (Ruff) and Jovil. The "new improved" shuttle type toroidal winders differ from older units by the addition of computer controls to the basic machines.

These offer some improvement, in the systems which have programmed acceleration and deceleration, to potentially reduce wire breakage. The new units offer stepping motor rotation of the core in place of older fixed or variable ratio drives. This method of driving the core could improve the positional placement of the individual turns. Rotation can be stepped in coordination with the counting of the turns, simplifying setup calculations regarding shuttle diameter, etc. The computer controlled units have the ability to store many program steps such as stops for taps. They also offer advantages in "tutoring" the operator for each sequential step of producing a coil. The improvement items discussed have little relation to the coils that must be hand wound.

Every plant visited expressed a desire for improved toroid winding capability. This particular need represents a clear consensus within the four participating subcontractors and the industry at large.

The development of the automatic and manually assisted toroidal winding equipment is needed due to the already large number of such toroids that are wound by hand. With the trends toward higher frequency switching power supplies, toroids will be used in increasing numbers having the following characteristics:

- Multifilar conductors
- Larger relative wire sizes
- Reasonable numbers of turns (100 or less)
- Restrictive center hole sizes.

Further development of this program will require a more detailed analysis of the toroid market requirements. For this report toroids were distinguished as large or small. The wound wire size was initially used for grouping. The detail needed to design and justify development of a toroidal winding machine is illustrated in the following tabularized questionnaire.

TOROID PRODUCT SPECIFICATION QUESTIONNAIRE

Core Specifications			Primary Winding			Secondary Winding			Secondary Winding				Current Winding Method (Use of Labor)		
I.D.	O.D.	Material	Wire Size	# Turns	Wires Per Turn	Wire Size	# Turns	Wires Per Turn	Wire Size	# Turns	Wires Per Turn	Qty. Per Year	% Shut	% Hook	% Hand

11.3 Benefits:

Detail cost data of the present toroidal winding operation is not available. One company representative noted that a "rule-of-thumb" for manual winding was 30 seconds per turn (as amortized over a scheduled 8-hour day). For the purposes of further economic evaluation of this opportunity, data compiled in the "generic company" profile will be used.

It is assumed that the automatic toroid winder could be designed to enable a single operator to manage two machines. For low quantity production, with wire lengths within its range, the automatic toroid winder would provide labor savings even on coils which can be produced by conventional equipment. Assuming 1 minute to load/unload the machine and 2 minutes to wind the coil, the production rate of one machine is 20 coils per hour (one coil each 3 minutes). If one operator can manage two machines, the toroidal production rate per person is 40 coils per hour.

11.4 Estimated Development Cost:

$800,000

The development cost for the two prototype (automatic and manual) machines is estimated at $800,000.

Calendar time is estimated at 24 months to completion.

Unit costs exclusive of development for the automatic machine are expected to be $85,000.

CURRENT GENERIC TOROIDAL HOOK AND HAND WOUND PRODUCTION DATA

	Annual Production Quantities	Current Manning	Coils Per Man Hour	Coils Per Year 100% Eff.	Coils Per Year 75% Eff.
Hook Wound - Small	5,985	.5			
- Large	6,840	.5			
	12,825	1.0	6.68		
Hand Wound - Small	13,965	2.0			
- Large	1,368	.5			
	15,333	2.5	3.19		
Totals Per Year -	28,158	3.5	4.19		
Proposed Machine - One Machine			20.0	38,400	28,800
Proposed Machine - Two Machines *			40.0	76,800	57,600

* One Operator

This project would save 2.5 equivalent persons per company. Annualized, at $8.00 per hour the direct labor savings is $38,400. When considering the variable manufacturing overhead ($14.00 per hour), the annualized savings is $67,200 per company.

Additional savings are expected from the decrease in scrap resulting from rough handling of the wire during manual and hook winding. It is estimated that the current scrap and rework is approximately 2% of annual production. This amounts to 563 coils per year. The direct labor value of each coil is estimated at $16.43. Annualized, the loaded direct labor value is $9,251. It is assumed that machine winding of these coils would eliminate half of this scrap and rework. A $5,000 savings due to quality improvement is reasonable.

The cost benefit assessment is based upon implementation of the automated machine. If, the machine can be utilized 75% of the scheduled hours for production, one person loading and unloading two machines is sufficient to meet the annual production requirements on a one shift basis. The cost benefits assessment is as follows:

Capital required for one machine: $85,000

Annual loaded direct labor savings: $67,200
Annual Quality Savings: $5,000
Total Annual Savings: $72,200
Simple Payback For Subcontractor: 1.18 Years

Air Force Benefits:

Assuming that the development costs are $800,000. With annual savings of $72,200. Sales statistics for the generic company are as follows:

- 93.0% of Sales are DoD
- 39.5% of Sales are Air Force
- 24.4% of Sales are AF/F-16

The first analysis is based upon F-16 benefit and assumes that no additional companies are solicited. Therefore, the AF/F-16 annualized savings is $17,616 per company or $70,467 for the 4 participating subs. If these assumptions are correct, 11.35 years of F-16 production/procurement is required to payback $800,000 of development, clearly unattractive.

The next analysis is based upon considering the Air Force program with no additional companies located. The annualized AF savings is $28,519 per company or $114,076 for the four participating subs. If these assumptions are correct, 7.01

years of AF procurement is required to payback the $800,000 development.

The last analysis considers an AF requirement for a 3 year payback. Using the "loaded" values to determine number of companies to achieve a three year payback on the estimated $800,000 development cost.

TOTAL ESTIMATED 3-YEAR SAVINGS/COMPANY - TOROIDAL WINDER

	One Company DL/w Overhead	No. Companies (3 Yr. PB)
Generic (100%)	$216,600	3.69
DoD (93.0%)	201,438	3.97
Air Force (39.5%)	85,557	9.35
AF/F-16 (24.4%)	52,850	15.13

It is believed that there are significantly more than 15 DoD/AF magnetics manufacturers who would use an automatic toroid winder that operated as described in this section. It is also possible that a commercial vendor would support the effort.

12.0 PRODUCING COIL BOBBINS FOR LOW QUANTITY MILITARY APPLICATIONS

12.1 Project Description/Objective:

Develop a flexible manufacturing cell for fabricating low quantity, custom, bobbins to meet the requirements of both the power supply design and the automatic bobbin winding machines. The cell machines would be able to construct a bobbin with the necessary termination pins and considerations for insulation.

NOTE: This project is not practical until the Standardization project, or its intent, is completed.

12.2 Background:

Present low quantity production of fairly complex electrical coils involves considerable effort in building up the core form onto which the coils(s) will be wound. Many sizes of rectangular insulated tubing are available for the magnetic core cross sections usually encountered. This tube stock is cut to the required length for the coil. End pieces are cut from similar material. The parts are assembled onto a rigid steel winding mandrel having side plates for support of the ends.

The action of the coil winding can exert considerable forces against the coil form ends. Hence, they must be secured well to the tube with pieces of tape and backed up by the mandrel side plates. Before removing the coil additional taping is required so it does not expand to an unacceptable width. Often the resulting coil is somewhat "soft" in width.

During assembly of the "C" (or "E", "I") shaped magnetic core, the parts are compressed and secured by bands. The function of the banding is twofold: 1) to close the magnetic gap and 2) to compress and secure the coil.

Coils can conservatively be designed narrower to minimize this "growth" and the resulting potential damage to adjacent coil turns. This implies that there will be less efficient use of the core window for the coil cross section. Often the "Next Size Up" must be chosen to assure the accommodation of the winding. In addition to the above technical complaints for this type of coil, its' use is also very labor intensive.

Molded bobbins are commonly used in commercial products. These bobLins have been especially designed for a given circuit (application) or family of circuits (applications). Availability of molded bobbins to the commercial magnetics manufacturer is partly because several (or many) medium quantity users are utilizing the same style standard E-I laminations produced by a few large suppliers of stamped laminations.

Many bobbins are also sold which include termination pins. These are often custom designed for a particular high quantity part or may have excessive pins for a class of coil used in many similar applications such as calculator and portable tool battery chargers. If the addition of termination pins could also be included in the designs as "attachable" or removable element, there could be considerable savings in the "Post Winding" termination operation.

12.3 Benefits:

If it is assumed that these costs are reduced by 50% in the "Winding" function and 33.3% in the "Post Winding Assembly" from current levels, the annualized benefits to the "Generic" company are as shown.

SAVINGS POTENTIAL OF BOBBIN MANUFACTURING CELL

	CURRENT OPERATION		ASSUMED OPERATION	
	Percent	Equivalent Persons	Percent	Equivalent Persons
WINDING (13 Persons)				
Taping	12.5%			
Stripping	7.5%			
Soldering	7.5%			
	27.5%	3.58	13.375%	1.79
POST WINDING ASSEMBLY (21 Persons)				
Taping/Laminating	10.0%			
Soldering	55.0%			
	65.0%	13.65	43.333%	9.10
		17.23		10.89

Net direct labor savings potential is 6.34 persons which represents an annualized savings of $97,382 (direct labor), $170,419 (loaded direct labor) per company.

12.4 Estimated Development Cost:

It is proposed to develop moldable bobbin designs to suit "families" of parts. Tooling techniques (such as sectioned molds, etc.) would be developed for low quantity production economics. This capability would enable the magnetics designer/manufacturer to optimize core material required to satisfy the expected operational environment.

The bobbin design features developed during this program would be coordinated with the existing capability found in currently available CNC bobbin winding equipment. The final phase would be developing the process for economically producing the molded bobbin cores.

The estimated development program to determine feasibility and define needs is estimated at $200,000. Development of bobbin designs and tooling for the 5 most common "families" of parts is estimated at $500,000 (including tooling).

Calendar time is estimated at 30 months to completion.

12.5 Implementation:

Implementation (utilization) would be gradual (phased) as characteristics are known by designers and as quick delivery becomes assured.

MATRIX OF OPPORTUNITIES

PROJECT NAME	ESTIMATED DEVELOPMENT COST	CAPITAL COST PER UNIT	NO. UNITS REQ'D	GROSS ANNUAL SAVINGS/ COMPANY	DoD COMPONENT (93.0%)	U.S.A.F. COMPONENT (39.5%)	F-16/SPO COMPONENT (24.4%)
1.0 Standardization	$450,000	$ 0		$295,680	$274,982	$116,794	$ 72,145
2.0 Wire Stripping Process Definition & Control	$ 0	$ 0		$ 20,000	$ 18,600	$ 7,900	$ 4,880
3.0 Encapsulation Process Definition & Control	$250,000	$ Low		$ 59,136	$ 54,996	$ 23,358	$ 14,429
4.0 Design/Selection of Materials	$ 0	$ 0		$ 12,500	$ 11,625	$ 4,937	$ 3,050
5.0 Wire Stripper	$375,000	$ 3,500		$ 64,189	$ 59,696	$ 25,355	$ 15,662
6.0 Wire Marker/Labeler	$225,000	$ 4,500		$ 24,864	$ 23,123	$ 9,821	$ 6,067
7.0 Wire Tensioner	$105,000	$ 3,500		$ 14,955	$ 13,908	$ 5,907	$ 3,649
8.0 Insulation Tape Preparer	$265,000	$ 8,000		$ 10,920	$ 10,155	$ 4,313	$ 2,664
9.0 Product Labeler	$145,000	$ 7,500		$ 13,674	$ 12,717	$ 5,401	$ 3,336
10.0 Automated Full Load Test Facility	$850,000	$165,000		$ 61,152	$ 56,871	$ 24,155	$ 14,921
11.0 Automated and Manually Assisted Toroidal Winder	$800,000	$ 85,000	1	$ 72,200	$ 67,146	$ 28,519	$ 17,616
12.0 Producing Coil Bobbins For Low Quantity Military Applications	$700,000		1	$170,419	$158,490	$ 67,315	$ 41,582

APPENDIX 1

MAGNETICS MANUFACTURING TECHNOLOGY

APPENDIX 1

MAGNETICS MANUFACTURING TECHNOLOGY

This Appendix presents background information to assist an unfamiliar person with details regarding some of the technology of manufacturing magnetics. The contents of this Appendix include the following sections:

- Magnetic Device Configurations
- Product Standardization
- Design Trends
  - Configurations
  - Wire Size, Shape and Type
  - Operating Frequencies
  - Magnetic Cores
- Insulation and Encapsulation
- Processing Techniques
  - Wire Stripping
  - Wire Marking
  - Solder Melt & Tin
  - Winding
  - Forming
  - Identification
  - Testing
  - Terminating

MAGNETIC DEVICE CONFIGURATIONS

"Magnetic Devices", as considered in this report are fabricated assemblies whose principal components are wire wound coils, magnetic cores, and mechanical components for mounting. A magnetic device can consist of one or more coil assemblies. For example, a two phase power transformer requires two coil assemblies and a three phase power transformer requires three coil assemblies. Some magnetic device designs utilize additional coil sections for "control" functions and may be described as magnetic amplifiers, regulators, etc. For these configurations there are more individual coil assemblies required than "one-per-phase". The DoD power supply

sub-contractor typically monitors the "pieces" of magnetics to be manufactured. A piece of magnetics (also known as a transformer) can commonly require several coils; often with different types of coils interleaved such as foil, heavy wire, fine wire, etc. This is an important consideration when collecting production statistics. In this report, coil production statistics refers to the actual number of "sub-component" coils wound, dressed, and encapsulated.

Coil assemblies usually consist of a primary winding and one or more secondary windings. The insulated tubular section that the magnetic wire is wrapped around is referred to as the "form". There are two basic coil forms found within the designs of the military magnetics suppliers. [These are the toroid (shaped like a doughnut) and the cylinder which is actually more rectangular].

An additional component of the magnetic transformer is the "core material" (which has magnetic properties and is metallic or compressed and bonded powder material). For toroids, the "doughnut" shaped core also serves as the form that the magnetic wire is wound around. For cylindrical coils, the magnetic wire is wound around an preformed "spool".

Cylindrically wound coils are then assembled with one of several core shapes ("C", "E", or "I") after winding. Cylindrical coils fall into two groups; 1) Coils using pre-manufactured spools (referred to as "Bobbins") and 2) Coils wrapped around a spool (referred to in this report as "Core Tubes") which is fabricated as part of the wire winding process. There is a substantial supplier industry for standardized magnetic cores and "spools" (bobbins). "Standard" bobbins and cores are utilized by DoD magnetics manufacturers whenever possible.

Since the magnetics manufacturer purchases low volumes, bobbin and core manufacturers are not motivated to produce to their special needs. To overcome this disadvantage, the DoD magnetics manufacturer will often modify (shaping or removal of flanges, addition of slots for wire lead routing etc.) a standard bobbin to meet his specific design requirements. In the extreme case, the "spool" is fabricated from elements as an inter-winding function and is classified as a "Core Tube" coil.

From a manufacturing viewpoint, the production designs are classified as 1) Toroids, 2) Bobbins, or 3) Core Tube. Each of these types of coils are

further differentiated by size (large or small) and wound material (wire, foil, strap). During this report, "large" and "small" was distinguished by wire size. Coils using wire size AWG 20-22 and larger were "large" coil, and coils wound from magnetic wire finer than AWG 20-22 were counted as "small" coils.

PRODUCT STANDARDIZATION

Design of the transformer is usually one of the final steps in the design of the avionics system. The transformer design is frequently modified during qualification of the first functioning units. Since this activity is accompanied by continual pressure to meet contractual schedule commitments, adherence to "manufacturing related" design standards is difficult. The results of this can be viewed when studying magnetics manufacturing. There is a great diversity of similar, but different, toroids, bobbins, and core tube coils that are mechanically assembled into a wide variety of similar, but different, packages for incorporation into the next assembly. Functionally, there are no apparent "manufacturing related" design standards within each of the companies visited. Additionally, there are no "industry" standards available to these companies.

Automation has been hampered by a lack of standards. It is interesting to note that the participating companies consider themselves competitors. They believe that in concept they could be producing portions of each others work mix. Yet, based on initial impressions, it is difficult to rationalize that each company is producing magnetic components to a common set of specifications for the same end customer.

DESIGN TRENDS

Configurations

Toroids - for many applications toroids offer improved electrical performance over other coil forms. Toroid designs additionally yield least weight and displaced volume over other coil forms. For this reason toroidal coils will continue to be the coil form of choice for many applications. The

predominant factor retarding increased usage is the manufactured cost. Toroids are most expensive to produce than other "Equivalent" coil forms. A "simple" toroid is more expensive to produce than a functionally equivalent "simple" bobbin. Winding machines exist for producing up to 36 "bobbin type" coils at a time. Toroids in the most efficient machine available are produced one at a time.

In the case of toroids they must often be hand wound since the center hole is too small to accommodate a shuttle suited to the wire size. One reason for this is the desire to select a core which is minimum in size to accommodate the selected wire. There are additional problems in laying multi-strand wires in an accurate and controlled manner to make efficient use of the space for the coil cross section.

Wire Size, Shape & Type

Due to the future trend to higher frequencies, there will be more magnetic devices, (many of which will be toroid wound) that will have heavier wires and fewer turns relative to the size of the core. In some instances, because of skin effect at high frequencies, these windings must be produced with several insulated strands in parallel (multifilar). This is a challenge to the coil winder. Toroid winders are advertised to be capable of handling certain wire sizes up to three strands. Bobbin winders must have separate wire tensioning systems for each strand and can therefore be quite difficult to setup and use. Stripping problems are multiplied (unless solder strippable insulation is acceptable).

The need for a greater number of strands, leads to the solution of using "Litz" wire. Litz wire is a wire made up of many individual enameled fine wires, usually bound together with a light thread of cotton or synthetic fiber. Litz wire is very difficult to mechanically strip. Chemical stripping is troublesome for multi-strand wire because of the difficulty in removing or neutralizing the stripping agent. Solder strippable Litz wire is probably the most practical type to use assuming it meets the temperature requirements of the application.

Operating Frequencies

Power supplies and converters are going to higher frequencies in order to save weight. As this happens, everything about the magnetic components become more critical. This includes: (1) the way the windings are placed relative to each other, (2) the type of conductors used (multifilar, foil, Litz wire), and (3) careful control of core characteristics.

Magnetic Cores

The methods of making, controlling, specifying, and measuring the magnetic device cores is a subject that needs a complete study in itself. Since it is outside the scope of this program it shall not be discussed beyond the following comment. Cores for magnetic devices will become an increasingly important issue in producing the power supplies for such needs as the F-16 program.

INSULATION AND ENCAPSULATION

Commercial magnetics manufacturing techniques almost exclusively employ solder strippable wire. This simplification has significantly contributed to the present day level of automation in commercial magnetics winding. Since the wire coating is employed to provide insulation from the other windings, a related processing variable is the type and quality of the coil encapsulation. None of the F-16 magnetics subcontractors employed a standard encapsulation process to all coils.

The trend to higher frequency coils will result in increase use of ferrite or powder core materials by all the magnetics suppliers. Maximum flux density of these materials is reduced with increasing temperatures (much lower than 180 C). Therefore, it would seem that in using high temperature rated wire (180 C and greater), the coil is being fabricated to operate at a temperature much higher than can be tolerated for core performance.

Questions of the coating integrity of 180 C wire have been raised and should be considered. This concern is usually related to the single coated vs. double coated wire. An additional parameter affecting coil performance and manufactured cost (not addressed here) is type of insulation. Use of single or double coated wire impacts the maximum amount of copper in a given "core" window. The insulation thickness becomes more significant with finer gage wires. Double coating, while providing less chance of pin holes, increases the thickness of the insulation (and cost). From a reliability standpoint, single coated 180 C wire should not be directly compared to the 220 C double coated wire used in military electronics. Single coated 180 C wire is probably more available since it is used extensively in commercial and consumer products. There is a difference of opinion in its use by the four vendors surveyed.

Use of high quality vacuum impregnation techniques should be considered as a means of improving overall insulation integrity of the coil. Vacuum impregnation improves the high temperature requirement by stabilizing the coil mechanically and providing improved heat transfer. Highly consistent, thorough impregnation may reduce insulation failures by filling the occasional void in the wire coating and by providing more uniform thermal characteristics.

PROCESSING TECHNIQUES

Wire Stripping

There are three basic means to strip insulation from wire. These are:

- Mechanical Stripping
- Thermal Stripping
- Chemical Stripping

There are a variety of shop aids employed to assist the winders and assembler with mechanical wire stripping. Hand held rotary files, mechanical cutters, and bench top conical rolls were common at most facilities. These machines along with x-acto knives and abrasive paper are used to remove the wire coating. Low temperature rated wire can be thermally conveniently stripped

and tinned simultaneously in a solder pot. Commercial manufacturers tended to use solder decontamination techniques in solder stripping.

The four aerospace subcontractors did not employ chemical stripping techniques as it poses both waste handling and operator difficulties.

Wire Marking

Termination leads are currently hand marked. Sometimes preprinted tapes are wrapped around the wires. A small desktop unit, programmable, could prepare tapes on demand, and placing the wire in a certain position would cause the machine to apply the tape label.

Solder Melt & Tin

Refers to the use of solder strippable wire. Since tinning is unavoidable, it is recommended whenever possible to concurrently use the heat of the solder bath to melt the insulation from the wire integral to tinning. The apparent identified concerns are 1) management of the residue insulation contaminant in the solder bath, and 2) prolonged "soaking" of the leads in the solder bath (for the purposes of melting the insulation) creating "paths" for drawing the solder into the internal voids of the "encapsulated" coil. Commercial vendors had better control over these processes.

Winding

There are two basic classes of wire winding found at the magnetics manufacturers visited. They are "common or simple" winding and "precision" winding. In simple winding, the winder is basically counting turns and locating the wire onto the "form" as required to meet "number-of-turns" and maximum dimensional requirements. Precision winding refers to the accurate "placement" of each turn of wire(s) so as to eliminate "cross-overs", and produce the smallest (most compact) coil. Cross-overs during winding are a common cause of inadvertent wire breakage during further processing of the "magnetic device". Crossovers are also a potential source of insulation failure.

An additional parameter associated with winding is "wire tension". Too little tension can produce a loose, hence dimensionally inconsistent coil. Too much tension can produce inadvertent wire breakage and insulation failure. Automatic wire tensioning devices and "precision" wire placement machines exist for the low volume supplier. However, a significant amount of "wire placement" and tensioning was being performed manually by the winder.

Forming

During winding, the winder frequently uses custom shaped block and mallet to "lightly pound" the coil to the proper "outside dimension". This process must be performed delicately as it can lead to unwanted wire breakage. However, "forming" is a required process to accompany "manual" winding in that an oversized coil is also useless (scrap).

Identification

Termination leads are currently hand marked. Sometimes preprinted tapes are wrapped around the wires. Finished parts are currently marked, for all practical purposes, with hand stamps.

Testing

100% of the magnetics parts are partially inspected at multiple times throughout the fabrication process. This condition holds at all of the participating DoD aerospace magnetics contractors. This universal high cost process has two components.

The first is the need to produce a thorough functional test. Current testing is frequently simply a turns ratio test and a continuity test. In some cases an insulation test is also conducted. Needed is a thorough, functionally based test, at frequency and load. The commercial consumer electronics manufacturer visited had the ability to actually record the results of their full function test loadings, and send those results to a central computer. The sub-contractors could only record the environmental cycle testing.

The second consideration is the amount of manual labor and time that goes into setup on these test stands.

Terminating

In the current operation wire terminations are all performed manually. Wire termination is a significant expense and involves a number of inter-related subjects. Successful reduction of this high cost activity will require coordinated improvements in several areas which the following paragraphs illustrate.

There are many automatic bobbin winders available with a high degree of programmability and capability for automatically terminating leads by wire wrapping on pins. In producing Mil Spec Magnetics, three items hold up practical use of such equipment: (1) low quantities of a particular product preclude the use of a specially designed bobbin with "built in" pins for wire termination, (2) tape is used extensively for securing start leads and insulating them from the subsequent turns to be wound, (3) higher voltage coils often require interleaved layer insulation.

APPENDIX 2

<u>DESCRIPTION OF "AS-IS" OPERATIONS</u>

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DESCRIPTION OF "AS-IS" OPERATIONS

A key cost element in producing power electronics is the cost of manufacturing the wire wound magnetic devices. Magnetics manufacturing is an integral manufacturing activity found within aerospace industries that design, produce, and assemble power related avionics.

GENERIC PROCESS FLOW

Magnetic transformer production consists of the following major steps.

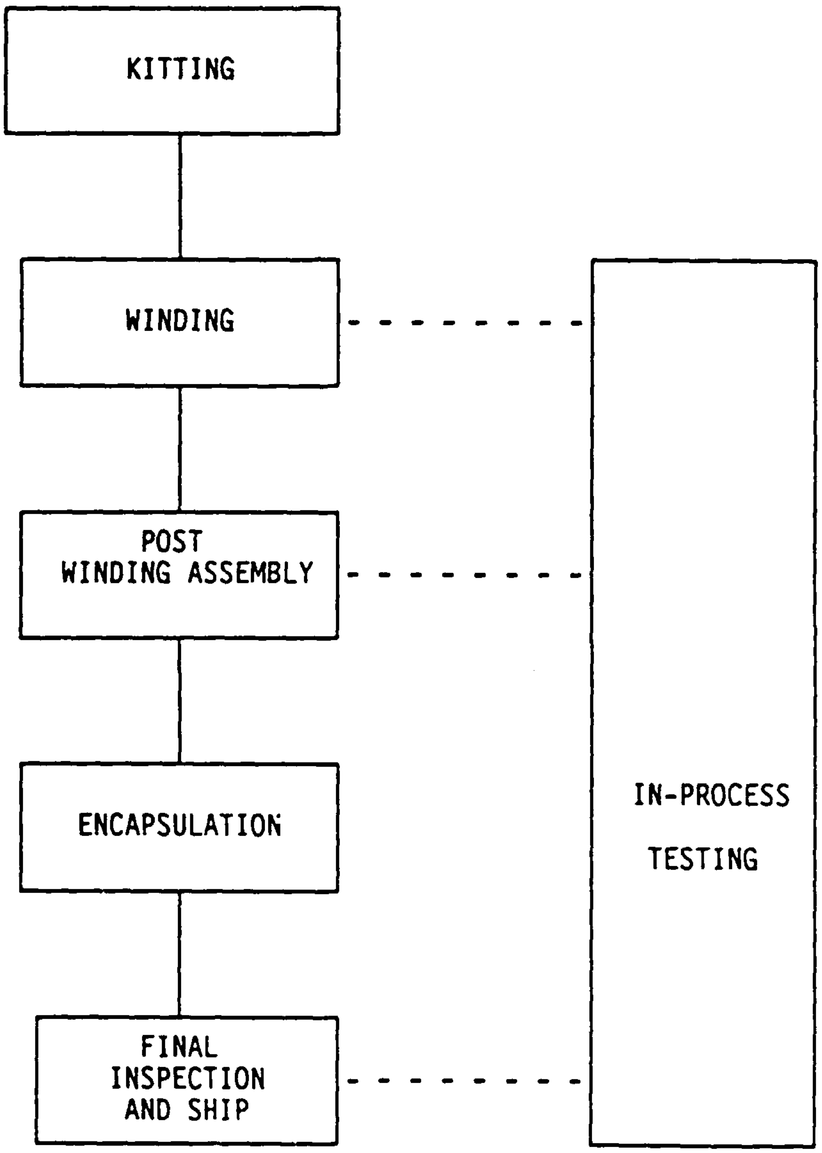
1. Kitting
2. Winding
3. Post-Winding Assembly
4. Encapsulation
5. Inspection/Testing/Identification/Packaging

These activities are illustrated in the following figure. Note that testing is not just a process performed at the end of the fabrication sequence. Rather it is performed at numerous times as a means of validating the "work-in-process" quality. A short narrative for each of these functions follows.

Kitting

The kitting function consists of combining the production order with the materials and technical data required to produce the specified lot size? of transformer assemblies. Kitting is not a costly operation to the magnetics manufacturer (Less than two persons). Fabrication (or purchase) of the mechanical hardware, used in "post-winding assembly", is not performed within the "magnetics operations" at the four subcontractors. The costs associated with acquiring the fabricated details was not included in this investigation. Minor modifications to catalogue bobbins and cores is common.

GENERIC PROCESS FLOW FOR MANUFACTURING MAGNETIC COMPONENTS



These minor modifications include drilling holes, fabricating slots and shaving or removing bobbin flanges. This minor rework is either performed by the kitting personnel or by the winders.

Winding

The winding function consists of wrapping the magnetic wire onto the appropriate spool or "form". There are two basic wound forms used; toroidal coils and cylindrical coils. Toroidal coils are typically referred to as "Toroids". Cylindrical coils are classed as "Bobbins" and "Coil Forms". The "Coil Forms" have a tubular core that may have either a rectangular or circular cross section. The tube core has been cut an appropriate length to become the "form" around which the wire is wrapped. It is for this reason that "Coil Form" coils might also be named "Core Tubes". "Core Tubes" are used as an alternative to selecting a catalogue "Bobbin" and may be fabricated from glass/epoxy or other materials with higher temperature capability than molded bobbins.

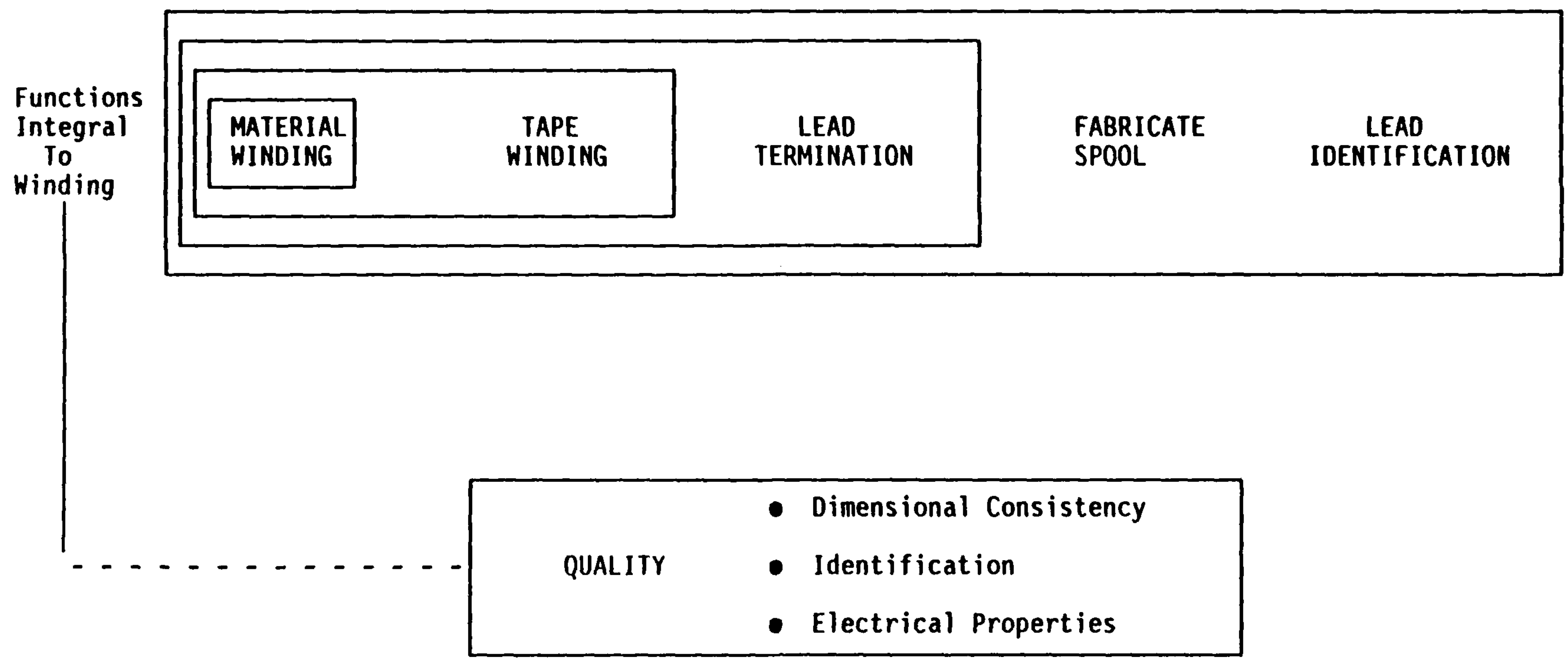
It is important to distinguish between these two varieties of cylindrical coils when performing a manufacturing analysis of the winding activity. Where a bobbin is a completed "form" that can include provisions for insulating primary windings from secondary windings, placement of start and finish leads, and terminations, the core tube "form" must functionally have these capabilities completed during the transformer fabrication. Most of this work is an integral part of the winding sequence.

Completing the winding process requires much more than "winding wire". The "Processes Required to Support Winding" figure identifies some of the process variables and activities needed to complete the winding process. When approaching the development of a solution for reducing winding costs, it is important to simplify when possible and then structure what is left. In the development of opportunities for the winding function it is useful to identify which steps could be performed during kitting (such as bobbin modification) and which tasks could be performed during post-winding assembly (such as testing or lead identification). What remains are activities that are integral to winding.

PROCESSES REQUIRED TO SUPPORT WINDING

- Small Wire
- Large Wire
- Strap
- Foil
- Multifilar
- Litz

- Double-Back Adhesive
- Teflon
- Polyester
- Mylar
- Polyimide
- Paper



The two most frequent activities observed during the present winding operations are 1) Wire winding and 2) Taping. It can be useful to distinguish between taping that is integral to winding (such as interlayer taping) from taping performed to isolate different windings of different coils. The boxes drawn around the functions required to support winding are to emphasize the following observations:

1. Toroid coil winding is essentially a material (wire, foil, or strap) winding operation.
2. Bobbin coil winding is essentially a wire winding and taping activity.
3. Core Tube coils require significantly more interwinding operational steps to produce a completed coil.

All four of the F-16 magnetics manufacturers produced "Toroid" and "Bobbin" coils. Not all of the manufacturers produced Core Tube coils. Seventy-four (74%) of all the coils produced by the four participating companies were toroids.

Toroidal Winding

The magnetics industry has three methods available to wind toroidal coils. They are 1) "Shuttle" type winding, 2) "Hook" winding, and 3) "Hand" winding.

All magnetics manufacturers visited use the "Shuttle" type toroidal machines as much as possible. Shuttle winding involves the use of a circular shuttle which must be looped through the toroidal core prior to winding. Operation of the shuttle winder begins with winding a predetermined amount of wire from the wire spool onto the shuttle "spool". The wire from the shuttle is then "unwound" around the toroidal core. Toroidal winding can be visualized as a "Last-Off, First-On" process. Restated, the last bit of wire taken from the wire supply spool is the first bit of wire wound onto the toroidal core. Hence shuttle winding requires the load/unload of the shuttle through the toroidal core and the wind/unwind of the wire from the shuttle for every coil. Once set up, "turns" of wire can be applied at a very high rate. Three technical obstacles with this process are: 1) shuttle is too

large to manuever through the center of the coil, 2) shuttle cannot accommodate the varied multifilar wire combinations, and 3) shuttle cannot provide appropriate tensioning for the particular wire size.

The primary alternative to shuttle winding is "Manual" winding. As the name implies, this process is entirely manual. In appearance, the manual winder presents an appearance similar to drawing a needle through a button. When heavier wire (or high numbers of multifilar) create a "strength" problem for the manual winder, the "Hook" winder is used to generate the force to conform the wires around the core. The "Hook" winder, while effective, represents a potential operator and process danger. The "powered" hook can lead to operator hand injury and excessive abuse of the wires by the action of the hook.

The winding equipment industry appears to be ignoring the toroid. The equipment available today is not significantly different from what was available forty years ago except for programmed rotation of the core and computer direction of winding sequences. Such is not the case for the bobbin.

Bobbin Winding

Commercial magnetics suppliers have generated the necessary demand to permit development of sophisticated bobbin winding machines. Machines are available to wind, terminate to integral tooling posts, and tape. Some machines are configured to wind up to 36 bobbins at a time. In all cases these machines have been developed for the high volume (millions of bobbins per year) production of a relatively few number of configurations for the consumer electronics industry. To date, the coil winding industry has not adapted this "mass production" technology to the low volume winders needs. As will be discussed later, the DoD magnetics designer has not demonstrated the desire to constrain his design to the "lower cost" capabilities of his manufacturing department.

Bobbin winding has been much more adaptable to automation then toroidal winding. From a wire dispensing viewpoint, bobbin winding is a "First-Off, First-On" process. Bobbins can be wound either by rotating the bobbin or "wrapping" the wire around a static bobbin ("fly-winding").

Present day production of low cost commercial bobbin type coils is the result of several design considerations in addition to the high volume "customer demand" and technical performance of the winding equipment. These include 1) use of solder strippable wire, 2) development of special bobbins designed to accommodate winding automation, accommodate or eliminate taping, and 3) provisions for wire termination by the winding equipment.

The bobbin should be a more economical coil form than the core tube. The statistics obtained from the participating subcontractors and portrayed in the "generic" company do not support this claim. The reason offered is that only limited productivity benefit is obtained from the bobbins utilized. The military magnetics manufacturers typically 1) modifies each "standard bobbin", 2) manually initiates and terminates each winding, and 3) applies a significant amount of insulation tapping to each bobbin coil.

Core Tube Winding

As can be seen by the "Processes Required to Support Winding", the requirements for this type of coil are more varied than either toroids or bobbins. For this "coil" sub-assembly, the actual winding costs are a small part of the total costs. The core tube coil form provides the greatest flexibility to the designer. The flexibility is obtained in exchange for higher manufacturing cost.

In both core tube and bobbin winding a significant amount of the wire placement and wire tensioning was manually provided by the winder. While this practice appears antiquated, the complexities of individually machine tensioning multifilar windings, while precisely placing each wire turn is significant. This condition has become alleviated with the development of servo controlled positioners. Modern winding machines can be configured for winding a particular coil with "software" in lieu of time consuming mechanical setups. The four participating subs are aware of this technology and appear to be in various stages of obtaining equipment having this capability.

Post Winding Assembly

This functional process is not a good candidate for a comprehensive single "integrated" improvement project. This part of the magnetics manufacturing operation differs dramatically between subcontractors. However, there are sub-function processes, such as wire stripping, marking, terminating etc., that do represent a common needs.

Encapsulation

Encapsulation represents a common requirement that does not appear to be consistently performed from one contractor to the next. The technology exists (and equipment is readily available) to economically pot, encapsulate, vacuum impregnate, varnish etc. The perceived opportunity can be summarized this way. If it is assumed that each of the four subcontractors is meeting Mil-Spec requirements, then three of them are paying more per coil than the lowest cost operation observed.

GENERIC COST STRUCTURE

This section presents a description of the "Generic Company". It is an average (composite) of the four participating subcontractors. Using "Generic Company" data allows candidate improvements to be evaluated without compromising the individual data from a particular company. The "Generic Company" data was reconciled with information and observations from other sources as well. The values used are believed to represent a diversified military "power supply" avionics manufacturer. The "Generic Company's" coil requirements are for large and small toroids, bobbins and core tubes. These coils are assembled into a wide variety of single and multiple phase transformers, inductors and amplifiers. The following "Production Survey" contains the detailed information regarding the "Generic Company".

Generic Company Description

Magnetics As-Is Functional Cost Questionnaire Data For Generic Company

Company Data (Write Company Name: Generic Magnetics Department/Division/Comp.

Number Participating Divisions Producing Magnetics - 1

Division 1 - Magnetics Department

Total Manufacturing Direct Labor Population

Division 1 - 300

Total Direct Labor Producing Magnetics

Division 1 - 55

Total Annual Sales Volume

Division 1 - $43,000,000

Annual DoD Sales Volume

Division 1 - 93.0% Total = $40,000,000

Annual Air Force Sales Volume

Division 1 - 39.5% Total = $17,000,000

Annual F-16 Sales Volume

Division 1 - 24.4% Total = $10,500,000

Annual F-16 ASD/SPO Sales Volume

Division 1 - Not Available

Product Configurations (For purposes of this study, we are interested in production of coils. For example, a three phase transformer typically requires 3 bobbin or core tube type coils.) The generic company produces 86,000 coils per year. These are distributed as follows: 1) 66,28% = 57,000 coils are toroids, 2) 10,000 bobbin coils, and 3) 19,000 core tube coils.

Toroids Produced Annually - 57,000

Small - 70% of toroidal mix

Division 1 - 39,900

Shuttle Wound - 50% = 19,950

Hook Wound - 15% = 5,985

Hand Wound - 35% = 13,965

Generic Company Description

Large - 30% of toroidal mix
- Division 1 - 17,100
  - Shuttle Wound - 20% = 3,420
  - Hook Wound - 40% = 6,840
  - Hand Wound - 40% = 6,840

Bobbins Produced Annually -10,000
- Small - 75%
  - Division 1 - 7,500
    - Magnetic Wire - 7,500
    - Strap or Foil - Very small quantities (0)
- Large - 25%
  - Division 1 - 2,500
    - Magnetic Wire - 2,500
    - Strap or Foil - Very small quantities (0)

Core Tubes Produced Annually - 19,000
- Small - 50%
  - Division 1 - 9,500
    - Magnetic Wire - 9,500
    - Strap or Foil - Very small quantities (0)
- Large - 50%
  - Division 1 - 9,500
    - Magnetic Wire - 90% = 8,550
    - Strap or Foil - 10% = 950
- Other Products (Wet Winds etc.)
  - Division 1 - None

Generic Company Description

Production Costs

Annual Magnetics Manufacturing Direct Labor Budget (Std. Hrs. Forecast)

- Standard Man-Hours Per Year - 1,920
- Production Hours (1920 x 55)
  - Division 1 - 105,600
- Rework Hours
  - Division 1 ______________
- Scrapped Hours
  - Division 1 ______________

Manpower Allocations (No. Persons) For Primary Division

- Direct Labor - Total = 50
  - Kitting - 1
  - Winding - 13
    - Toroids - 5
      - Small - 3.5
        - Shuttle Winding - 1
        - Hook Winding - 0.5
        - Hand Winding - 2
      - Large - 1.5
        - Shuttle Winding -.5
        - Hook Winding - .5
        - Hand Winding - .5
    - Bobbins - 3
      - Small - 2
      - Large - 1
    - Core Tubes - 5
      - Small - 2
      - Large - 3
  - Post Winding Assembly - 21
  - Encapsulation - 11
  - Testing - 7

Generic Company Description

- Prototyping - Included Elsewhere
    - Winding ______________
    - Post Winding Assembly______________
    - Encapsulation______________
    - Test______________
- Material Handling - 2

Indirect Labor

- Supervision - 3
- Inspection - 2

Other (Such as Manufacturing Engineering) -1

Labor Rates

Hourly Compensation

- Winders - $8.00
- Assemblers - $8.00
- Inspectors - $8.00

Program/DoD Pricing Rates (Var OH =____, DEB =_____, G&A= _____)

- Winders - $14.00
- Assemblers - $14.00
- Inspectors - $14.00 Annual Material Costs

Winding

- Toroidal Cores ______________
- Wire ______________
- Tape ______________

Assembly

- Other Core Materials ______________
- Wire ______________
- Tape ______________
- Solder ______________

Encapsulation ______________

Generic Company Description

Functional Labor Costs of Division 1 (Total DL = 100%)

- Kitting - 100% = 1 Person
  - Assemble Documentation - 40%
  - Obtain Purchase Material - 20%
  - Assemble Material ______________
  - Modify Purchase Material ______________
  - Fabricate Other Material ______________
  - Build Kit - 40%
- Winding - 100% = 13 Persons
  - Job Setup - 2.5%
  - Machine Winding - 45%
    - Toroids - 10%
    - Bobbins - 10%
    - Tube Cores - 25%
  - Hand Winding - 20%
    - Toroids - 20%
    - Bobbins ______________
    - Tube Cores ______________
  - Inter-winding Testing - 0%
  - Inter-winding Taping - 12.5%
    - Toroids - 2.5%
    - Bobbins - 2.5%
    - Tube Cores - 7.5%
  - Wire Identification - 5%
  - Wire Processing - 15%
    - Stripping - 7.5%
    - Soldering - 7.5%
  - Other - 0%

Generic Company Description

- Post Winding Assembly - 100% = 21 Persons
    - Banding - 5%
    - Taping/Laminating - 10%
    - Soldering - 55%
        - Lead Tinning - 5%
        - Lead Attachment - 25%
        - Lug Termination - 20%
        - Wire Splicing - 5%
        - PCB -
    - Mechanical Assembly - 10%
    - Assembly Identification - 5%
    - Additional Wire Processing - 15%
        - Winding - 0%
        - Stripping - 15%
- Encapsulation - 100% = 11 Persons
    - Prepping - 30%
    - Bonding - Included Elsewhere
    - Impregnation - 15%
    - Potting - 25%
    - Varnishing - Included Elsewhere
    - Cleanup - 15%
    - Finishing/Sanding - 15%
- Testing - 100% = 7 Persons
    - Receiving - 10%
    - In-Process - 50%
    - Final Inspection - 15%
    - Supervision/Administration - 25%
- Material Handling - 100% = 2 Persons
    - Prepping - 40%
    - Tinning - 40%
    - Final Bracket Assembly - 20%

Generic Company Description

Quality Data

Top 5 Sources of Rework

1 Sizing, Out of Dimension, Physical Tolerance

2 Wire Damage, Broken Leads

3 Electrical Test Failures (High-Pot, etc.)

4 Number of Turns

5 Rebanding Core

Top 5 Sources for Scrapping Production

1 Wire Damage to Flexible Leads

2 Internal Short (Open Winding)

3 Physical Dimension Problems

4 Off Turns

5 Other Electrical Test Failure

Annual Pieces Started - 88,580

Annual Pieces Produced - 86,000

Annual Pieces Reworked - 3% Pieces Started = 2,580

Annual Pieces Scrapped - 3% Pieces Started = 2,580

APPENDIX 3

STUDY APPROACH

APPENDIX 3

STUDY APPROACH

The initial task was to characterize the four DoD/aerospace magnetics manufacturers operations. This consisted of collecting the necessary technical, economic and production statistics needed to perform a preliminary assessment. All four companies participated in completing the "Magnetics As-Is Functional Cost Questionnaire" contained in this section. The questionnaire evolved to the detail presented in this report. The questionnaire can be used to "qualify" additional companies for participation/consideration/applicability for future joint magnetics development activity.

The information for this program was collected by the participating subcontractors and compiled by the Battelle team. Two plant visits to each company and numerous phone conversations ultimately contributed to the formation of a "composite" view of a typical magnetics manufacturing organization. The composite view was influenced by visits to "Other" DoD Magnetics Manufacturers, Equipment Vendors, Commercial Magnetics Manufacturers, and Battelle Experienced Opinion. The final result of this effort was the formation of the "Generic Magnetics Department/Organization". Since it was vital to preserve the confidentiality of the participating companies, cost benefit analysis information presented in this report is based on data from the "Generic Company".

Magnetics Production Survey

Magnetics As-Is Functional Cost Questionnaire Revised 4/22/88

Company Data (Write Company Name: ______________________________)

Number Participating Divisions Producing Magnetics _______

Division 1 ______________

Division 2 ______________

Division 3 ______________

Total Manufacturing Direct Labor Population

Division 1______________

Division 2______________

Division 3______________

Total Direct Labor Producing Magnetics

Division 1______________

Division 2______________

Division 3______________

Total Annual Sales Volume

Division 1______________

Division 2______________

Division 3______________

Annual DoD Sales Volume

Division 1______________

Division 2______________

Division 3______________

Magnetics Production Survey

Annual Air Force Sales Volume

Division 1______________

Division 2______________

Division 3______________

Annual F-16 Sales Volume

Division 1______________

Division 2______________

Division 3______________

Annual F-16 ASD/SPO Sales Volume

Division 1______________

Division 2______________

Division 3______________

Product Configurations (For purposes of this study, we are interested in production of coils. Foe example, a three phase transformer typically requires 3 bobbin or core tube type coils.)

Toroids Produced Annually ______________

Small

Division 1______________

Shuttle Wound______________

Hook Wound______________

Hand Wound______________

Division 2 ______________

Shuttle Wound______________

Hook Wound______________

Hand Wound______________

Magnetics Production Survey

Division 3 ______________

Shuttle Wound ______________

Hook Wound______________

Hand Wound______________

Large

Division 1 ______________

Shuttle Wound______________

Hook Wound______________

Hand Wound______________

Division 2 ______________

Shuttle Wound______________

Hook Wound______________

Hand Wound______________

Division 3 ______________

Shuttle Wound ______________

Hook Wound______________

Hand Wound______________

Bobbins Produced Annually______________

Small

Division 1 ______________

Magnetic Wire______________

Strap or Foil______________

Division 2 ______________

Magnetic Wire______________

Strap or Foil______________

Magnetics Production Survey

Division 3 ______________

Magnetic Wire______________

Strap or Foil______________

Large

Division 1 ______________

Magnetic Wire______________

Strap or Foil______________

Division 2 ______________

Magnetic Wire______________

Strap or Foil______________

Division 3 ______________

Magnetic Wire______________

Strap or Foil______________

Core Tubes Produced Annually

Small

Division 1 ______________

Magnetic Wire______________

Strap or Foil______________

Division 2 ______________

Magnetic Wire______________

Strap or Foil______________

Division 3 ______________

Magnetic Wire______________

Strap or Foil______________

Magnetics Production Survey

Large

Division 1 _______________

Magnetic Wire _______________

Strap or Foil _______________

Division 2 _______________

Magnetic Wire _______________

Strap or Foil _______________

Division 3 _______________

Magnetic Wire _______________

Strap or Foil _______________

Other Products (Wet Winds etc. - Please note in margin.)

Division 1 _______________

Division 2 _______________

Division 3 _______________

Production Costs

Annual Magnetics Manufacturing Direct Labor Budget (Std. Hrs. Forecast)

Standard Man-Hours Per Year _______________

Production Hours

Division 1 _______________

Division 2 _______________

Division 3 _______________

Rework Hours

Division 1 _______________

Division 2 _______________

Division 3 _______________

Magnetics Production Survey

Scrapped Hours
- Division 1 ______________
- Division 2 ______________
- Division 3 ______________

Manpower Allocations (No. Persons) For Primary Division
- Direct Labor
  - Kitting ______________
  - Winding ______________
    - Toroids
      - Small ______________
        - Shuttle Winding______________
        - Hook Winding______________
        - Hand Winding______________
      - Large ______________
        - Shuttle Winding______________
        - Hook Winding______________
        - Hand Winding______________
    - Bobbins
      - Small ______________
      - Large ______________
    - Core Tubes
      - Small ______________
      - Large ______________
  - Post Winding Assembly ______________
  - Encapsulation ______________
  - Testing ______________

Magnetics Production Survey

Prototyping_______________

Winding _______________

Post Winding Assembly_______________

Encapsulation_______________

Test_______________

Material Handling _______________

Indirect Labor

Supervision _______________

Inspection _______________

Other (Such as Manufacturing Engineering)_______________

Labor Rates

Hourly Compensation

Winders _______________

Assemblers _______________

Inspectors_______________

Program/DoD Pricing Rates (Var OH =_____, DEB =_____, G&A= _____)

Winders _______________

Assemblers _______________

Inspectors _______________

Magnetics Production Survey

Annual Material Costs

Winding

Toroidal Cores ______________

Wire ______________

Tape ______________

Assembly

Other Core Materials ______________

Wire ______________

Tape ______________

Solder ______________

Encapsulation ______________

Functional Labor Costs of Division 1 (Total DL = 100%)

Kitting - 100% = ____ Persons

Assemble Documentation ______________

Obtain Purchase Material ______________

Assemble Material ______________

Modify Purchase Material ______________

Fabricate Other Material ______________

Build Kit ______________

Winding - 100% = ____ Persons

Job Setup ______________

Machine Winding ______________

Toroids ______________

Bobbins ______________

Tube Cores ______________

Magnetics Production Survey

Hand Winding ______________

Toroids ______________

Bobbins ______________

Tube Cores ______________

Inter-winding Testing ______________

Inter-winding Taping ______________

Toroids ______________

Bobbins ______________

Tube Cores ______________

Identification ______________

Wire Processing______________

Stripping ______________

Soldering ______________

Other ______________

Post Winding Assembly - 100% = ____ Persons

Banding ______________

Taping/Laminating ______________

Soldering ______________

Lead Tinning ______________

Lead Attachment ______________

Lug Termination ______________

Wire Splicing ______________

PCB ______________

Mechanical Assembly ______________

Magnetics Production Survey

Identification _______________

Additional Wire Stripping _______________

Encapsulation _______________

Prepping _______________

Bonding _______________

Impregnation _______________

Potting _______________

Varnishing _______________

Cleanup_______________

Finishing/Sanding _______________

Testing _______________

Material Handling _______________

Final Assembly _______________

Quality Data

Top 5 Sources of Rework

1 ______________________________

2 ______________________________

3 ______________________________

4 ______________________________

5 ______________________________

Magnetics Production Survey

Top 5 Sources for Scrapping Production

1 ______________________________

2 ______________________________

3 ______________________________

4 ______________________________

5 ______________________________

Annual Pieces Started ______________

Annual Pieces Produced ______________

Annual Pieces Reworked ______________

Annual Pieces Scrapped ______________

DESIGN TRENDS

Configuration

____

____

____

Wire Size, Shape, and Type

____

____

____

Operating Frequencies

____

____

____

Magnetics Production Survey

Shielding

Insulation

Testing

Terminating

Packaging

Wire Stripping

Magnetics Production Survey

Comments

APPENDIX 4

GLOSSARY

APPENDIX 4

GLOSSARY

"C" core - magnetic "tape" (laminate) wound core, bonded, annealed, cut, polished, and etched for two matched "C" shaped cores. These will then be inserted into the E coil(s) and mechanically strapped together.

"E" core - an "E" shaped stamped lamination of magnetic material usually used in combination with an "I" piece. These laminations range from about .001 in. to .020 in. thickness and are "stacked" to form the desired core cross section.

"Flexible leads" - usually multistrand pretinned copper leads with thermoplastic jacket. Coils are usually wound with "solid" or single conductor magnet wire. A flexible lead is joined to this conductor, insulated, and secured to the external lead and has ability to stand repeated flexure.

"form" - the inside insulating material of a solenoid type coil in which the wire is wound. This usually conforms to the cross section of the magnetic core.

"gapping of cores" - the magnetic core circuit may often include an "air" gap for proper performance. This often is filled or controlled through use of a nonmagnetic "sham" material (mylar, polyamide, brass)

"Hi-Pot" (Dielectric) - high voltage insulation breakdown tests from individual windings to the metallic core or to other windings. "Hi-Pot" is actually the tradename for test equipment.

"Hook Winder" - pneumatic cylinder actuated machine used to assist manual toroidal winding

"Litz" wire - a multiconductor strand of wire made up of insulated conductors bound in a single lightweight sheath of nonconductive wound filament or thread

"magnetic component" - aviation industry term for inductors.

"precision winding" - each successive turn of coil laid down beside the last; no gaps or overlaps permitted

"primary winding (primary)" - for power transformers - usually the input power windings

"secondary winding(s)" - for power transformers - the output winding(s)

"Shuttle winder" - automatic machine for winding toroids. Requires circular shuttle to run through the toroidal core.

"solder strippable wire" - wire coated with "varnish" type insulation which burns off when dipped or emersed in molten solder (known as "solder pot stripping")

"strap or foil winding" - magnetic wound material other than wire.

"tinning" - the application of molten solder or tin to a (usually) copper surface, free of oxide, so "wetting" occurs

"transformer core" - the magnetic components of a transformer

"transformer inductor" - a slang term implying an inductor coil utilizing a magnetic core rather than "air" (nonmagnetic) core

"winding cross-overs" - occurrence of turns of wire "crossing over" previous turns resulting in points of high stress on the wire.

"wire solderability" - condition of wire to accept "tinning" - usually the degree of oxidation or the surface chemistry of the wire. Wire can have a "shelf life" with respect to solderability

Bobbin Coil - a coil wound on a bobbin like one piece coil form

corona - the undesirable phenomena wherein a flow of ions occurs due to local areas of very high voltage gradients (volts/mil). This can be destructive of surrounding solid insulation. Voids in the impregnation of highly stressed coils can support corona with resulting potential failure. Corona generates RFI. Proper design and manufacturing eliminates corona.

encapsulation - usually refers to the casting of a coil into a shape defined by an outer form

impregnation - the technique of applying a low viscosity insulating liquid or epoxy thoroughly into a coil cross section. The object is to completely displace all gas spaces with the insulating fluid for improved electrical and thermal integrity

magnetics - inductors

Mil Std 454 - General specification for design and construction of electronic components

Mil-T-27 - Applicable DoD Military Specification document for qualifying

multifilar - a coil turn made up of a "bundle" (or strand) of insulated conductors which are electrically "paralleled" by stripping and joining the ends

potting - same as encapsulation

Quality Std 9856 - Government specification controlling inspection requirements. (Spec number 45208 for smaller components)

SN10 "High Temperature Solder" - 90% Tin, 10% Lead

SN63 "Low Temperature Solder" - 63% Tin, 37% Lead

Toroid Coil - a coil wound in the form of a toroidal helix

Varnishing - a term for coating with a liquid material which will set up as a solid insulating coating upon drying or curing

APPENDIX 5

EQUIPMENT VENDOR SURVEY

APPENDIX 5

EQUIPMENT VENDOR SURVEY

The International Coil Winding Association Show in Chicago was attended in October 1987. From this show contacts with equipment vendors were begun. This and subsequent effort was performed to assure that current "off the shelf" technology was considered during candidate improvement evaluation.

COMMERCIAL VENDORS

During the period from February 29, 1988, to March 15, 1988, extensive telephone inquires were made to characterize candidate suppliers of the various types of coil winding, testing systems, encapsulation systems and soldering systems. Sources of names and addresses of candidate suppliers included: 1987 International Coil Winding Show, Electronic Engineers Master Catalog, Coil Winding International Incorporating Electrical OEM & Rewinding Magazines, and previous experience of Battelle staff. The list of suppliers and some notes related to the inquiries follows. This information is not represented as being complete. It is provided as a service to the report reader who may wish to initiate inquiries responding to a presented idea.

COIL WINDING MACHINE VENDORS

Accuwinder Engineering Company, 942 Amelia Ave., San Dimos, CA 91773, (714) 592-4475; Dr. Werner R. Kirchner, President, sent literature about computer controlled bobbin winding machines. Computer programs are written BASIC. Basic machine features are programmable electronic controller, traverse direction indicators, circuit breaker protection, and motor speed control.

Amacoil, Inc., P.O. Box 2228, 2100 Bridgewater Rd., Aston, PA 19014, (215) 485-8300; Josef K. Eigenmann, sent literature. The company only offers bobbin winding machines with many programmable controllers.

Bachi, Inc., 1201 Ardmore Ave., Itasca, ILL 60143, (312) 773-5600; Tom Zoltek, Area Sales Representative. The company offers semi- to fully automated bobbin machines. Detailed system specifications for each bobbin winder are listed at the end of this appendix.

Coast Magnetics Co., 5333 W. Washington Blvd., Los Angeles, CA 90016, (213) 936-6188; Dev Dosaj, Sales Manager, sent company literature and machine catalog. Coast Magnetics only offers bobbin winding machines. The prices for the 3 models and accessories are listed at the end of this appendix.

Coil Winding Equipment Co., Inc., P.O. Box 660, Railroad Plaza, Oyster Bay, NY 11771, (516) 922-5660; Anne Brown, Applications Engineer, met Battelle project team members at EEIC/ICWA ' 87 Exhibition in Chicago. Full general catalog and a current price list were brought back to Battelle for information and reference.

Computerized Coil Winders, Inc., 5 West Kenosia Ave., Danbury, CT 06810, (203) 744-6715; Klaus Thiel, President. The company's computerized toroidal coil winders have base prices range from $5650 to $6850, depending upon gear head size. Once manually loaded, the entire coil winding operation is performed automatically.

EPM Corporation, 8866 Kelso Dr., Baltimore, MD 21221, (301) 686-7800; Tom Manaing, Vice President - Sales, said the company makes a variety of coil production equipment including both rotating spindle winders and fly-winders. These programmable winding machines are extremely versatile and can process a variety of different specifications. Price list can be referred at the end of this appendix.

Fabrico, Inc., 3500 Atlanta Industrial Dr., Atlanta, GA 30331, (404) 696-9192;

Fisher-Baker Corporation, 3108 Industrial 31st Street, Ft. Pierce, FL 34946, (305) 466-0750; Ronald L. Peck, General Manager, offers both toriodal winders and bobbin winders. The electronically controlled, servo-driven, toriodal winders, like other manufacturers' toridal machines, perform automatic coil winding operation once toroids are loaded manually. The company's single-spindle and multiple-spindle bobbin machines are also servo driven electronically controlled.

Geo. Stevens Manufacturing Co., Inc., 6001 N. Keystone Ave., Chicago, 77IL 60646, (312) 588-1300; K.C., sent a full line of catalog and also price list. This company manufactures bobbin winding machines from hand fed winders to automatic winders. Price range goes from $1,500 for a hand winder to as much as $51,300 for a micro processor based heavy duty transformer winder.

Gorman Machine Corp., 7 Burke Drive, Brockton, MA 02401, (617) 588-2900; Henry LaBelle, Sales, sent bulletins describing toroidal and bobbin winding machines. The company offers one model of hook winding machine, 2 models of shuttle machines, and 5 models of bobbin machines. The hook winding machine (model name: Hustler, base price: $2,700) has automatic rotation of toroidal coil and has wide range of core and wire sizes (cores to 2" O.D. and wires to #12 AWG). The 2 shuttle machines (model name: Productor B, base price: $4,800 [4" winding head]; model name: 920A, base price: $7,600 [4" winding head]) have similar features. The primary difference between the 2 models is that the more automatic 920A model is designed for applications that involve infrequent reversal of core rotation. Henry mentioned that Gorman produces 4

bobbin winding machine models. The most simple bobbin winder is the Simplex winder which is designed as a basic hand-guided winding machine. Bobbineer winder is another model that performs one bobbin at a time. It has counter control panel and programmable traverse speeds. The other 2 are dual spindle winders that performs 2 bobbins in a cycle. No prices are listed for the bobbin winding machines.

Jovil Mfg. Co., Inc., Precision Rd., Danbury, CT, 06810, (203) 792-6700; Keith Fredlung said their toridal machines are capable of handling cores ranging from 1/32" I.D. all the way up to 8" O.D., with a wire range from #46 to #12. Jovil also has micro-processor programmable count controllers. Base prices and additional attachments were also mailed to Battelle.

Marsilli USA, Inc., 1919 Lakeview Drive, Fort Wayne, IN 46808, (219)436-0362; John Tite, V.P. & General Manager. The company offers various bobbin winding models. Marsilli bobbin winding system is design for large production of all kinds of coils where termination on axial pins and tags is possible. These flexible systems have automatic load/unload stations, and pallet conveyor lines. Bobbin winding models can have as many as 18 spindles at a time.

Necoa, Inc., 9321 Philadelphia Rd., Baltimore, MD 21237, (301) 574-4960, Mark B. Eitholtz, Sales and Marketing,

Midland Engineering & Machine Co., 9630 West Allen Ave., Rosemont, IL 60018, (312) 678-4113; Lorraine Clemmensen. The company offers coil taping machines for both bobbins and toroids.

Tanac, Inc., 425 W. 10th St., San Pedro, CA 90731, (213) 831-6780; Clinton Neal,

United Technical Products, 6 Headley Place, Fallsington, PA 19054, (215) 736-2517;

Universal Mfg. Co., Inc., 1168 Grove Street, Irvington, NJ 07111, (201) 995-4647; Martin Mayer, Sales Manager,

TESTING SYSTEMS

Wayne-Kerr

VACUUM ENCAPSULATING SYSTEMS

Epoxylite Corp., 1066 Arundel Ave., Westerville, OH 43081, (614) 882-8511;

Hull Corporation, Hatboro, PA 19040, (215) 672-7800; Steve Wilson, Sales, sent catalog and quotes. Two vacuum potting systems (5A-24 and 5ARA). 5A-24 model (base price: $36,500) has larger capacity than model 5ARA (base price: $24,000).

SOLDERING SYSTEMS

Kahle Engineering, 3344 Hudson Ave., P.O. Box 877, Union City, NJ 07087, (201) 867-6500;

OK Industries, Inc., Ford Executive Plaza, Yonkers, NY 10707, (914) 969-6800; Ingrid Zenske, Sales Representative. Soldering bath machines have base price of $3,000.

Zeba Electric, 50 William Park Way, E. Henover, NJ 07936, (201) 887-1399; Heinz Hauser, District Manager, sent machine information.

E.P.E. Corporation, P.O. Box 5238, Manchester, NH 03108, (603) 669-9181; Ernie Woyma (Spectrum Tech., E. Lake, OH 44094, 216-951-4455), Regional Sales Manager, sent materials about dip soldering machines.

Hollis Engineering, Inc., Charron Ave., Box 1189, Nashua, NH 03061, (603) 889-1121; Ray Haysles (Ames Division of Haysles Distributing, P.O. Box 360449, Cleveland, OH 44136, 216-572-1455) will return call soon...........

Pace Inc., 9893 Brewers Ct., laurel, MD 20707, (301) 490-9860; Ernie Woyma of Spectrum Technology also represents this company's products. Mr. Woyma sent information including price list to Battelle.

DISPENSING SYSTEMS

Sealant Equipment & Engineering, Inc., 21000 Hubbell, Oak Park, MI 48237, (313) 967-2111; Carl Schultz, Jr., Regional Sales Manager,

Liquid Control Corp., 7576 Freedom Ave., N.W., P.O. Box 2747, North Canton, OH 44720-0747, (216) 494-1313; Steve Coffman, Applications Engineer,

APPENDIX 10

CHARACTERIZATION OF OTHER MANUFACTURERS

APPENDIX 10

CHARACTERIZATION OF OTHER MANUFACTURERS

Hadley

Robert M. Hadley Company, Inc., 750 West 51st Street, Los Angeles, California 90037, (213) 234-9091. Attention - Christopher Waian, Vice President - Operations.

The Robert M. Hadley Company was visited February 17, 1988, to review their magnetics manufacturing operations. They describe their operation as being a custom manufacturer of high quality and reliable transformers and inductors. The transformer group includes power (single or multi-phase), audio, saturable, and encapsulated high voltage designs. Inductors and reactors are the power, audio, and saturable types. Hadley's orientation is principally for military (MIL-T-27) or space flight applications.

They wind most core types and materials, including ferrites, toroids, C-cores, and laminations. Materials used for winding coils include copper foil for high current applications and heavy gauge to ultra-fine copper wire. Roughly two-thirds of the magnetic units weigh less than a pound.

Hadley has been a military magnetics supplier since 1933. Total personnel at their facility is approximately 100. They produce their products in a 20,000 square foot facility.

Hadley further describes themselves as "one of a dozen" companies in the United States that supply military magnetics on a subcontract basis. They prefer (and are very willing) to supply design engineering services to a potential customer during their design cycle in order to arrive at a producible transformer design. Pre-coordination with the customer during design occurs for 50% of their volume.

The magnetics manufacturing operations viewed at Hadley were typical of equipment and processes present at the four participating subs. Notable observations are as follows.

- The profession staff at Hadley are very fluent with the technology of designing and manufacturing transformers.

- Hadley provides a high performance vacuum encapsulation to achieve thorough encapsulation for the majority (possibly all) of their aerospace quality coils. The system used is capable of rapidly achieving a 50 millitorr vacuum.*

- Hadley is producing large quantities of toroids (25%), bobbins (50%), and core tube coils (25%). Their operation is considered comparable to the "generic company" descriptions though they do not produce as many toroids.*

- Hadley performs electrical tests on 100% of production units after winding, prior to impregnation, as well as at final test. The final testing includes a simulated thermal and electrical load.*

- Hadley's manufacturing and test capabilities are equivalent to or exceed those of the four project particpants.

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* Data taken from Hadley brochure.

AT&T New River Valley Works
Radford, Virginia

AT&T's New River Valley facility is the largest single magnetics manufacturing facility in the world, covering nearly 500,000 sq. ft.

There is an unusual diversity of product successfully manufactured to high quality commercial and DoD requirements. Product ranges include:

- Core Tubes
- Bobbins
- Toroids
- Quantities of one to over 100,000 per year
- Assemblies as well as components
- Small surface mount devices to large 3-phase power transformers

Part of the plant mission is to support AT&T's worldwide requirements for maintenance transformers. These are typically quantities of one requiring deliveries measured in hours, not days.

AT&T has developed effective proprietary manufacturing techniques and equipment for their higher volume production requirements. They also have purchased a variety of equipment from both Asia and Europe.

Processes are under exceptional control compared to the industry. There is a strong commitment to full function component testing. Data is automatically sent to a central location that prepares daily graphical production and quality data.

A total of 70 manufacturing engineers support magnetics production, including 35 on site.

Functional product and manufacturing requirements at AT&T were similar to those of the other vendors surveyed. While there were clearly high volume commercial applications that were not directly comparable, an estimated 1/3 to 1/2 of the New River Valley people were working on lower volume requirements similar to the F-16 vendor requirements.